An Assessment of Air Pollutant Effects from a Nickel Smelter on Forest Vegetation at Thompson, Manitoba, 1977 and 1982

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AN ASSESSMENT OF AIR POLLUTANT EFFECTS FROM A NICKEL SMELTER ON FOREST VEGETATION AT THOMPSON, MANITOBA, 1977 AND 1982

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ABSTRACT

Forest vegetation in nine jack pine (Pinus banksiana Lamb.) and black spruce (Picea mariana (Mill) BSP) communities in the Thompson area were examined to assess the impact of air pollutants from the Inco smelting complex. Sites were located on two transects representing the main dispersion zones of airborne emissions.

In 1977 and 1982 physical measurements and density values were recorded for the trees and shrubs while the lower vascular plants were described on the basis of density, dominance and frequency. The condition and percent cover of bryophytes were evaluated.

In this five-year evaluation no apparent relationship was found between tree and shrub density and distance from the emission source. The effects of air pollutants did not appear as a factor in determining distribution of understory vascular plants. The greatest increase in species number occurred at the site closest to the smelter.

Ordination of jack pine sites based on frequency-cover indices of understory species showed a relationship between sites which were in the same relative position on the two transects while the ordination of black spruce sites did not indicate any definite trends.

Bryophytes which were the most sensitive members of coniferous forest vegetation experienced a decline in cover with increased exposure to air pollutants. Bryophyte cover increased with increased distance from the smelter. Some improvement in bryophyte condition was evident at close-in sites over the five-year period which may reflect decreased smelter emissions during this time.

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1. INTRODUCTION

In Thompson, Manitoba, nickel smelting has been carried out since 1961 by Inco Limited. Gaseous and particulate emissions are discharged from a 152-metre stack. Principal pollutants are sulphur dioxide (SO_2) and heavy metal particulates containing nickel, iron, copper, lead, cadmium and zinc.

The Thompson smelter is centered in the boreal forest ecosystem of northern Manitoba (55° 43'N, 97° 52'W). When air pollutants are released into the atmosphere they have the potential to impact the surrounding environment. Coniferous forests of jack pine (Pinus banksiana Lamb.) and black spruce (Picea mariana (Mill.) BSP) are dominant in the Thompson area.

Air pollutants can be removed from the atmosphere and may impact these forests by wet and dry deposition processes; they may be adsorbed onto plant and soil surfaces or subjected to various biochemical actions. Gaseous emissions such as SO_2 can cause vegetation injury symptoms such as foliar chlorosis, necrosis, premature foliar loss and others which may ultimately alter the growth and development of plants (Malhotra and Blauel, 1980).

Heavy metal particulates can be directly deposited to the soil or may be physically trapped by plant surfaces and subsequently be washed from the forest canopy to the soil surface . Some metals can be incorporated into plant cuticles (Hemphill and Rule 1975). It is well documented that heavy metal accummulations in soils may reach levels which become toxic to plants (National Research Council,

1981). Gas exchange, photosynthetic rate, transpiration and light availability can be directly and indirectly affected by heavy metal deposition (Malhotra and Blauel, 1980).

During the first 14 years of the Thompson smelter's operation the Canadian Forestry Service in response to a request by the Manitoba government conducted annual surveys of forest condition in the area. Between 1970 and 1975 several more intensive surveys followed. Foliar damage to vegetation in the area was recorded by Blauel and Hocking (1974) and was attributed to SO_2 and metal particulate emissions.

In 1977, the Environmental Management Division of the Province of Manitoba and the Northern Forest Research Centre of the Canadian Forestry Service established a joint federal/provincial research program. This study was designed to determine the environmental impact of airborne sulphur dioxide and heavy metal particulates emitted from northern mining smelters on surrounding forest ecosystems.

In the Thompson area, nine study locations composed of mature jack pine and black spruce were selected as permanent study sites (Figure 1). Each site was located in a transition area with a pure stand of black spruce on the north aspect and jack pine on the south. Each site was located in the primary dispersion sector, southeast and southwest of the smelter (Table 1).

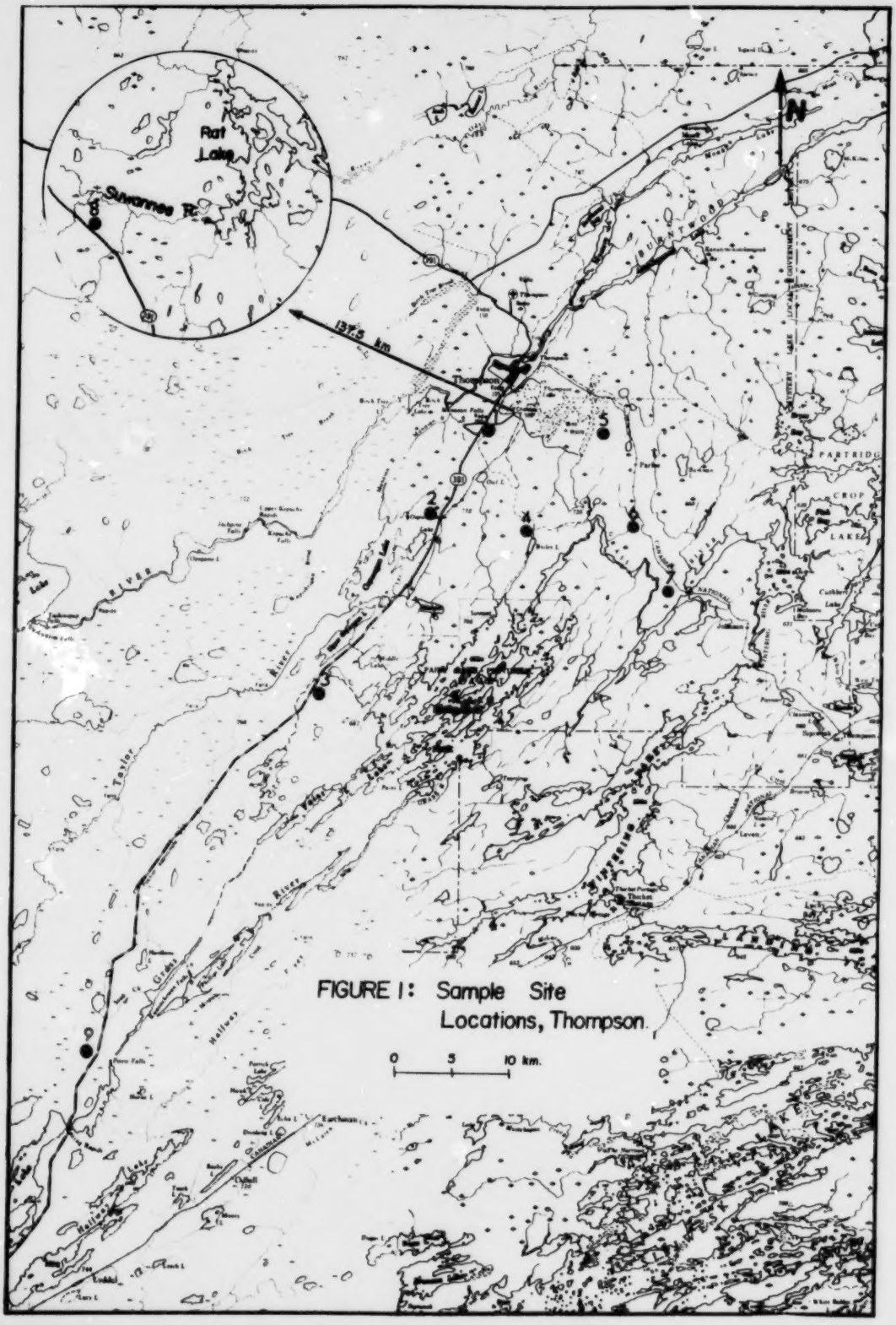

FIGURE 1: Sample Site Locations, Thompson.

Table 1: Study Site Locations, Thompson

Site Number	Direction From Stack	Distance From Stack (km)	Latitude	Longitude
1	SW	3.99	55° 41' 22"	97° 54' 12"
2	SW	12.23	55° 37' 10"	97° 57' 18"
3	SW	31.75	55° 28' 39"	98° 8' 16"
4	S	10.97	55° 37' 7"	97° 49' 13"
5	SE	8.99	55° 41' 35"	97° 43' 14"
6	SE	15.71	55° 37' 5"	97° 40' 35"
7	SE	21.83	55° 34' 11"	97° 37' 30"
8	NW	132.00	56° 00' 00"	100° 00' 00"
9	SW	66.03	55° 12' 35"	98° 24' 20"

A major component of the federal/provincial program was a complete vegetation inventory of all study sites. All natural plant communities were described and documented to provide a benchmark of forest condition and to facilitate long term biological monitoring. In 1982, the Environmental Management Division conducted a five-year evaluation of all study sites. This report provides the results of this biomonitoring study.

2. STUDY OBJECTIVES

This study was designed to provide a five-year evaluation of forest biomonitoring sites established in jack pine and black spruce stands of the Thompson area to determine the environmental impact of air pollutants emitted from the Inco smelter on forest vegetation.

3. STUDY METHODS AND PROCEDURES

3.1 Vegetation Inventory

The natural plant communities within each study site were identified, described and documented in detail. The purpose was to detect and benchmark any existing environmental impact of air pollutants and to establish baseline conditions for long term biomonitoring. The forest vegetation of all study sites was stratified into the three broad strata of tree-shrubs, low shrub-herbs and cryptogams. Two complimentary sampling networks were designed to satisfy this objective, one for the larger tree-high shrubs and the second for the lower shrub-herb strata.

3.2 Tree and High Shrub

A 10 metre square macroplot was established in each stand of jack pine and black spruce at all selected study sites. In each macroplot, vegetation was stratified into the two major communities of trees and high shrubs. Shrubs were defined as woody plants taller than 50 cm.

All trees within each macroplot were identified and physical condition, abundance and tree diameter were assessed. Each tree was tagged and mapped within the macroplot. Three representative trees from each study site were selected for age and height measurements. Age was determined by measuring radial growth at DBH (1.4 metres) and height was measured by a haga altimeter.

All shrubs within the macroplot were identified, their physical condition was evaluated, and a stem count was recorded. The location of each shrub clone within the macroplot was mapped. The density of shrub clones within the macroplots was used as a measure of abundance. Crown width measurements were used to calculate cover.

3.3 Low Shrub-Herb

Six one-metre square microplots were established in a predetermined random location which was standardized for each large macroplot. In each microplot the vascular community was further stratified into the following components:

Low Shrubs: woody plants less than 50 cm high with an indefinite number of stems arising from a single rootstock.

Tall Herb: non-woody species between 15 to 50 cm in height.

Low Herb: non-woody species less than 15 cm in height.

Cryptogam: the common ground moss, liverwort and fern layer

The above strata were sampled for species composition, density, frequency and percent cover in each of the six microplots per study site. Individual species members were examined for foliar condition concurrently with sampling procedures. Only the most common mosses and liverworts were included in the vegetation descriptions largely because of the high degree of specialization required to do a detailed investigation of these groups.

For the purpose of this study, an individual plant was defined as one being rooted within the quadrat and having a distinct and single root origin. This system was difficult to apply in the

case of species in the Ericaceae family where creeping stems were often rooted at the nodes. In such cases, a decision was made to count each rooted segment as an individual. The cover of each species was also difficult to determine accurately with a one-metre square quadrat. To increase the accuracy of cover estimates the large quadrat was subdivided into four equal units and measures of density and cover were taken in each 1/4 quadrat and then totalled. All microplots were photographed so that a permanent record of vegetation was available for future reference.

The vegetation data collected from each microplot were used to calculate density, relative density, dominance, relative dominance, frequency and relative frequency for each species in the shrub-herb stratum of each study plot. These data were used to calculate association values of understory species for comparison between study sites.

3.4 Analysis Procedures

To evaluate the vegetation data for density, dominance and frequency the following formulae were used:

$$\text{Density} = \frac{\text{number of individuals}}{\text{area sampled}}$$

$$\text{Relative Density} = \frac{\text{density for a species}}{\text{total density for all species}} \times 100$$

$$\text{Dominance} = \frac{\text{total basal area for aerial coverage values}}{\text{area sampled}}$$

$$\text{Relative Dominance} = \frac{\text{dominance for a species}}{\text{total dominance for all species}} \times 100$$

$$\text{Frequency} = \frac{\text{number of plots in which species occurs}}{\text{total number of plots sampled}}$$

$$\text{Relative Frequency} = \frac{\text{frequency value for a species}}{\text{total frequency values for all species}} \times 100$$

$$\text{Association Value} = \frac{\% \text{ cover} + \% \text{ frequency}}{2}$$

The association values were used in the computer program Decorana to ordinate the sample sites. Ordinations of species and samples are obtained by a method of detrended correspondence analysis. The axes represent a gradient of standard deviations. A small difference in standard deviation between sites indicates these sites have a high similarity whereas a large difference in standard deviation shows low similarity between sites (Hill, 1979).

4. RESULTS AND DISCUSSIONS

4.1 Jack Pine Sites

4.1.1 Tree Stratum

A summary of the tree inventory data for the jack pine sites (1977, 1982) is found in Table 2. Characteristics of diameter, height, age, mortality and basal area were used to compare trees between sites over the five-year study period.

In general, sites with a low density of jack pine had trees with larger diameters, likely a result of reduced competition. The greatest increase in diameter over the five-year period occurred in sites 4 and 6, the lowest increase in sites 3 and 8. The remaining sites exhibited fairly similar increases in diameter. Height measurements were variable and difficult to assess in the jack pine. Inconsistencies found in measurements over the five-year period were likely the result of sampling error.

There was not a marked increase in mortality over the five year study period. At the time of establishment (1977), site 4 had experienced the greatest mortality. The greatest increases in total living basal area were found at sites 1, 7 and 9 where no mortality occurred. In general, all sites were found to have an increase in total living basal area except site 5 where a slight decrease was recorded. Site 8 had the lowest total living basal area which could be anticipated because of the lower age class and subsequent smaller size of trees.

Table 2: Summary of Tree Data from Jack Pine Biomonitoring Sites, 1977 and 1982

Plot	Tree Species	Mean Diameter (cm)		Mean Height (m)		Mean Age (yrs)		Total Stems Living		Total Stems Dead		Percent Mortality		Basal Area Plot (cm^2)		Total Living Basal Area/Plot (cm^2)	
		1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982
1	Pinus banksiana	23.53	23.95	19.4	18.8	74	79	6	6	1	-	14.3	-	2633.38	2720.55	3661.27	3859.48
	Populus tremuloides	15.02	15.68	-	-	-	-	5	5	-	-	-	-	918.53	1000.00		
	Populus balsamifera	11.80	13.30	-	-	-	-	1	1	-	-	-	-	109.36	138.93		
2	Pinus banksiana	14.34	14.81	16.9	17.1	81	86	17	16	6	1	26.1	5.6	2810.59	2824.96	3581.26	3722.23
	Picea mariana	22.20	23.90	-	-			2	2	-	-	-	-	770.67	897.27		
3	Pinus banksiana	20.73	20.84	20.8	20.2	84	89	7	7	3	-	30.3	-	2498.53	2524.16	2505.60	2542.26
	Populus tremuloides	3.00	4.80	-	-			1	1	-				7.07	18.10		
4	Pinus banksiana	13.62	14.25	13.0	14.5	87	92	12	11	10	1	45.5	8.3	1840.02	1833.90		
	Picea mariana	7.27	8.21	-	-			7	7	1	-	12.5	-	325.29	409.78	2754.82	2824.39
	Populus tremuloides	11.58	13.10	-	-			5	4	2	1	28.6	25.0	589.51	580.71		
5	Pinus banksiana	15.37	15.76	16.4	17.5	79	84	15	14	8	1	34.8	7.1	2912.59	2860.31		
	Populus tremuloides	11.62	15.88	-	-			5	4	-	1	-	20.0	842.66	800.27	3771.15	3682.64
	Picea mariana	4.50	5.30	-	-			1	1	-	-	-	-	15.90	22.06		
6	Pinus banksiana	13.91	14.73	13.0	13.7	82	87	14	13	1	1	6.7	7.7	2241.73	2316.16	2241.73	2316.16
7	Pinus banksiana	14.33	14.61	18.4	17.7	85	90	19	19	10	-	34.5	-	3247.55	3276.66	3573.28	3771.85
	Picea mariana	13.60	15.00	-	-			2	2	-	-	-	-	425.73	495.19		
8	Pinus banksiana	8.88	9.04	12.4	12.8	53	58	28	26	-	2	-	7.1	1852.84	1784.30	1952.86	1952.67
	Picea mariana	5.53	7.25	-				4	4	-	-			100.02	168.37		
9	Pinus banksiana	13.23	13.68	18.2	13.1	77	82	22	22	7	-	24.1		3146.37	3379.73	3146.37	3379.73

The growth parameters measured in the tree stratum did not appear to correlate with distance from the local source of air pollution emissions. The trees currently on the study sites were all well established prior to the smelter becoming operational in 1960. The majority of mature trees would have been 50 years or older at that time. Variations in site quality, density and composition must be recognized in quantitative evaluations of this type. Effects from these natural variations are difficult to separate from those of industrial emissions.

4.1.2 Shrub Stratum

Table 3 summarizes the shrub inventory in the jack pine stands for 1977 and 1982. Total number of shrubs ranged from 0 to 101 between the various study sites. Alnus crispa was the dominant shrub found in all sites except 4 and 6 where Salix dominated. Shrub species, number and frequency was site related and no indication of smelter influence was evident.

During the five year study period no increase was recorded in the number of shrubs per site, however decreases in numbers were observed in all sites except 9 for clones of Alnus crispa. This decrease in number of clones was accompanied by an increase in total number of stems per site in all sites except 5 which would suggest an ecological change is occurring rather than an anthropogenic effect of atmospheric emissions.

Table 3: Summary of Shrub Data from Jack Pine Biomonitoring Sites, 1977 and 1982

Plot	Shrub Species	Mean Height (m)		Mean Crown Width (m)		Mean no. Stems/Shrubs		Total Shrubs/Plot		Total no. Stems/Plot		% Cover		Mean % Mortality/Plot	
		1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982
1	Alnus crispa	2.46	2.63	1.08	1.20	5.88	8.75	101	88	594	770	145.80	122.19	0.67	12.80
	Viburnum trilobum	-	0.90	-	0.60	-	1.00	-	-	-	1	-	0.28	-	0.00
2	Alnus crispa	2.20	2.83	1.36	1.14	10.32	13.84	57	56	588	775	90.82	62.80	0.00	1.79
3	Alnus crispa	2.36	2.98	1.13	1.34	5.90	8.67	83	72	490	624	101.40	123.83	0.41	13.25
	Ribes spp.	0.71	3.67	0.43	2.03	1.30	13.00	6	3	8	39	0.94	7.80	0.00	50.00
	Salix spp.	1.50	-	0.60	-	1.00	-	1	-	1	-	0.28	-	0.00	100.00
4	Viburnum trilobum	0.58	-	0.55	-	2.50	-	2	-	5	-	0.48	-	0.00	100.00
	Salix spp.	2.00	1.80	0.85	1.10	7.00	6.00	1	1	7	6	0.57	0.95	28.60	0.00
	Shepherdia canadensis	0.70	0.60	0.45	0.50	4.00	5.00	1	1	4	5	0.16	0.20	0.00	0.00
5	Alnus crispa	2.15	2.34	1.23	1.12	7.59	8.16	49	45	372	367	75.32	55.19	0.00	8.16
6	Betula papyrifera	0.75	0.90	0.34	0.20	1.00	1.00	1	1	1	1	0.09	0.03		0.00
	Salix spp.	1.30	1.77	0.54	0.90	1.75	2.33	4	3	7	7	1.23	2.33		25.00
7	Alnus crispa	2.78	3.23	1.81	1.61	12.20	14.05	41	40	500	562	97.06	88.26	0.00	6.98
	Salix spp.	7.00	-	3.50	-	1.00	-	1	-	1	-	9.62	-	0.00	
	Viburnum trilobum	0.74	-	0.71	-	1.50	-	4	-	6	-	1.92	-	0.00	100.00
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
9	Alnus crispa	2.42	3.23	1.82	1.61	15.20	18.33	6	6	91	110	15.89	27.10	0.00	0.00

4.1.3 Understory

The identification, description, documentation and analysis of the understory or lower stratum is an onerous task due to species number and diversity as well as site variability.

To facilitate interpretation of the large data base the understory composition is presented as a frequency cover index (% cover + % frequency ÷ 2) for each species by study site.

The index values were compiled into an association table or table of species diversity for each year and are found in Appendix A-1 (1977) and A-2 (1982). Specific inventory information for each study site is provided in table format in Appendix C. This includes information on species composition, abundance and values of density, dominance and frequency.

The distribution of species in the understory can be derived from the association tables for both years. Species distribution does not appear to be affected by distance from the smelter source but related to site quality as were the tree and shrub data.

In Table 4 the understory characteristics are summarized for distribution and percent change in association value over the five-year study. The number of plant species increased in all study sites except 2, 3 and 7. At site 3, the number remained constant while site 7 decreased by one species and site 2 by three species. The remaining sites increased by one to five species per site. This increase in number did not appear to be associated with distance from the smelter. Species number at the control sites showed similar increases to sites 1 and 5 which are closest to the smelter.

Table 4: Summary of Understory Characteristics in Jack Pine, 1977 and 1982

Study Site	No of Species in Understory		% Change in Association Value 1977-1982		
	1977	1982	% Negative	% Positive	% No Change
1	15	19	32	63	5
2	13	10	47	27	26
3	14	14	12	88	0
4	19	22	48	35	17
5	17	20	14	67	23
6	18	23	32	60	8
7	16	15	50	35	15
8	9	12	33	58	8
9	8	12	25	50	25

The percentage change in association value from 1977 to 1982 reflects a similar pattern as that for the change in species number. Sites 2, 4 and 7 experienced the largest negative change in association value or correspondingly the smallest positive change. A positive change is a desirable change in terms of increased plant diversity as reflected from frequency and cover. Site 3, located farthest from the smelter in the southwest transect, was found to have the highest percent positive change (88%). However sites 1 and 5, located closest to the smelter in their respective transects (Figure 1), were also found to have a relatively high percent positive change at 63% and 67% respectively. Similar to the change observed in species number and distribution, species diversity did not appear to be related to distance from the smelter as reflected in the association index value.

4.1.4 Bryophytes

In both years, an association between distance from the pollution source and bryophyte distribution was not apparent. In 1977, the greatest number of species was found at site 2 which had nine species. Sites 7 and 9 also showed high species diversity while sites 1, 5 and 8 each with two species present had the lowest diversity. The remaining sites were intermediate in species numbers. Over the five-year period there was a reduction in number of species at several locations including sites 2, 3, 7 and 9. The greatest decrease occurred at site 2 which lost three species. Species numbers increased at sites 5, 6 and 8; the largest increase was found at sites 5 and 8 (Appendix A-3 and A-4).

The percent bryophyte cover was determined to emphasize the importance of this strata at individual sites (Figure 2). Although some sites have high species numbers it does not necessarily follow that bryophytes comprise a large percentage of the cover.

Table 5 illustrates a general trend of increasing bryophyte cover with distance in the jack pine stands for both 1977 and 1982. Cover values for individual moss species are presented in Appendix A-3 and A-4. Both sites 3 and 8 which had low bryophyte cover were an exception to this trend. In the case of site 3, shrub cover appears to be an influence. Sites 3 and 1 were found to have the lowest cover of bryophytes. In both cases shrub density was exceptionally high in comparison to other sites. It could be anticipated that this dense shrub cover is a limiting factor in bryophyte presence. However, bryophytes are known to be sensitive to air pollution (LeBlanc and Rao, 1975), and the location of site 1 close to the smelter would suggest that emissions are also contributing to the particularly low bryophyte cover observed.

In the case of site 8, a large portion of the ground cover was comprised of the lichen Cladina rangiferina, 82% was present in 1977 and 50% in 1982. As a consequence of this high occurrence of ground lichen the bryophyte cover was reduced. The lichen cover is unique to site 8; no other sites had a strong ground lichen component.

The increase in percent cover at all locations except site 7 over the five year period suggests an improvement in the bryophyte condition. However, a substantial increase was apparent only at sites 2, 4, 6 and 8.

Table 5: Summary of Herb and Bryophyte Cover, Jack Pine, 1977 and 1982

Site	% Herb Cover			% Bryophtye Cover			Total	
	1977	1982	%Δ	1977	1982	%Δ	1977	1982
1	82.0	114.5	+39.6	0.3	0.5	+ 66.6	82.3	115.0
2	54.5	45.3	-16.8	13.0	42.0	+223.0	67.5	87.3
3	68.4	84.7	-23.8	1.7	3.5	+105.8	70.1	88.2
4	151.9	90.8	-40.2	15.9	27.7	+ 74.2	167.8	121.8
5	35.5	51.0	+43.6	2.8	7.7	+175.0	38.3	58.7
6	197.0	109.0	-44.6	31.0	62.0	+100.0	228.0	171.0
7	101.7	52.4	-48.5	76.3	75.5	- 1.1	178.0	127.9
8	147.4	97.8	-33.6	7.0	34.3	+390.0	154.4	132.1
9	46.0	71.5	+55.4	77.4	79.0	+ 2.1	123.4	150.5

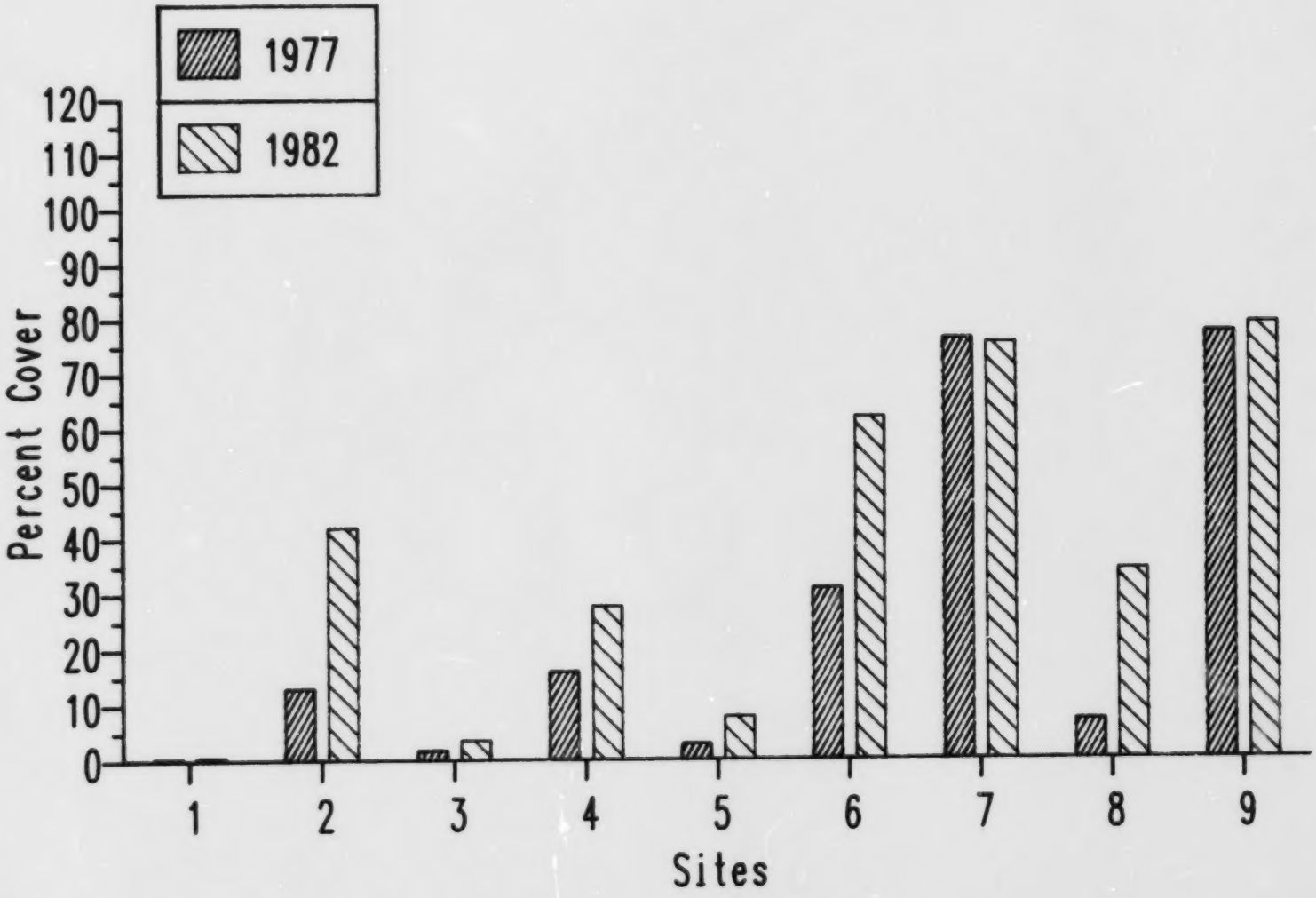

Figure 2: Percent Bryophyte Cover in Jack Pine, 1977-1982.

General observations of bryophyte condition in the jack pine stands in 1977 indicated a higher occurrence of leaf and shoot injury than in 1982. This injury was characterized by a browning or burning appearance. Also, a higher degree of injury occurred at sites which were close to the pollutant source. Only a small portion of healthy moss was evident at site 1. Burning symptoms on Pleurozium and Dicranum were noted at site 2 and Ptilidium was also in poor condition. At site 3 burn symptoms were apparent on a small portion of Hylocomium and Hypnum. The condition of Pleurozium, Hylocomium, and Dicranum at site 4 was poor, showing some burn symptoms. Site 5 also suffered from severe burning of mosses and in some of the microplots only burnt remnants were found. In all microplots of site 6, Pleurozium showed signs of burning. Injury of bryophytes was not observed at sites 7, 8 and 9 which are situated furthest from smelter emissions. The damage to mosses was not as evident in 1982 and burn symptoms were noted only at site 4.

4.1.5 Ordination Analysis

The ordination of jack pine stands within the nine study sites is graphically presented in Figures 3 and 4 for 1977 and 1982 respectively. The ordination process allows for evaluation of the vegetative communities for each forest site and for comparison of sites on a relative ecological basis. The five-year comparison provides a quantitative evaluation of vegetation change within the forest ecosystem.

In Figure 3, the ordination of 1977 data clearly selected out three outliers, sites 2, 8 and 9. The remaining six sites were

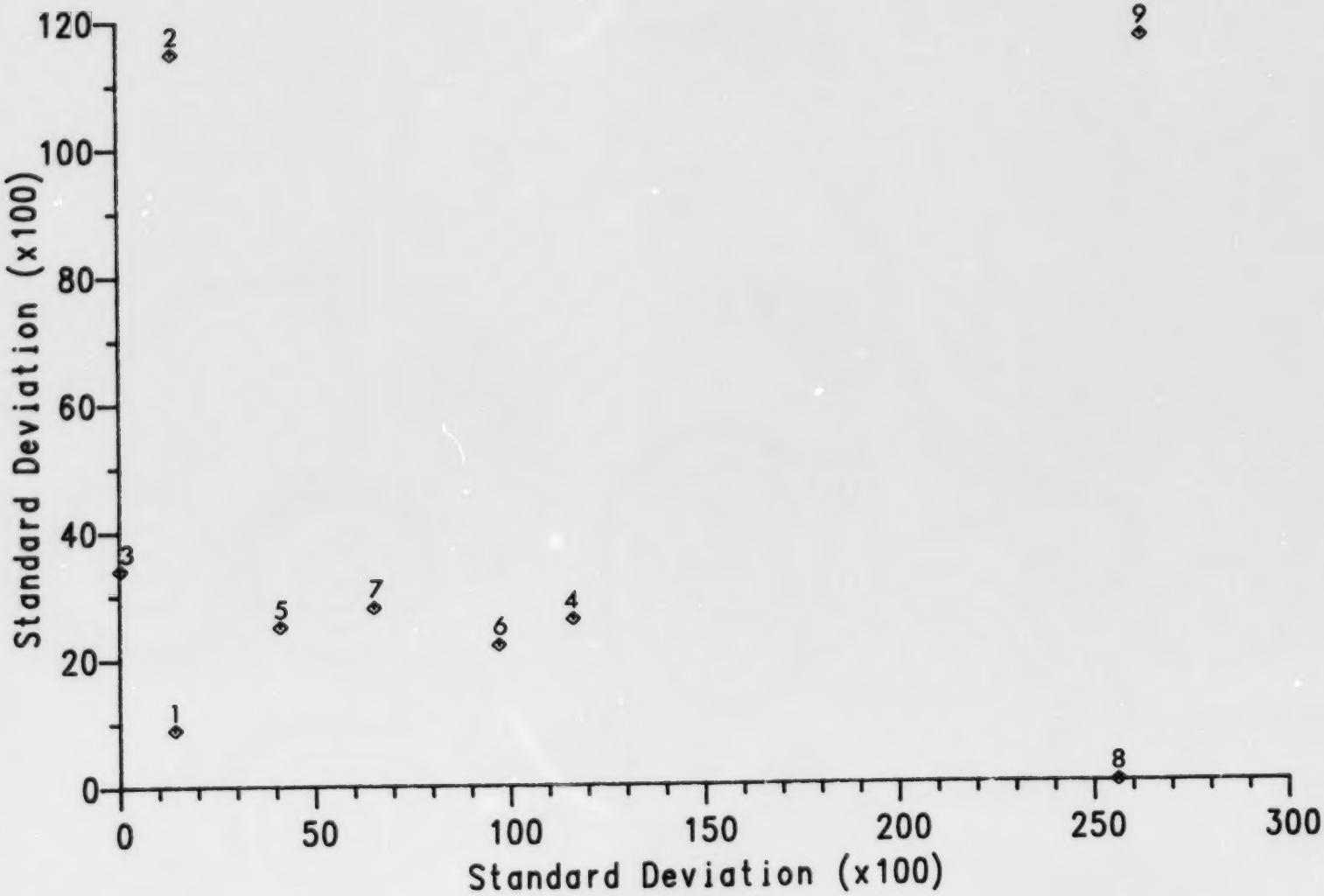

Figure 3: Ordination of Jack Pine Stands Based on Association Values of Understory Vascular Plants, 1977.

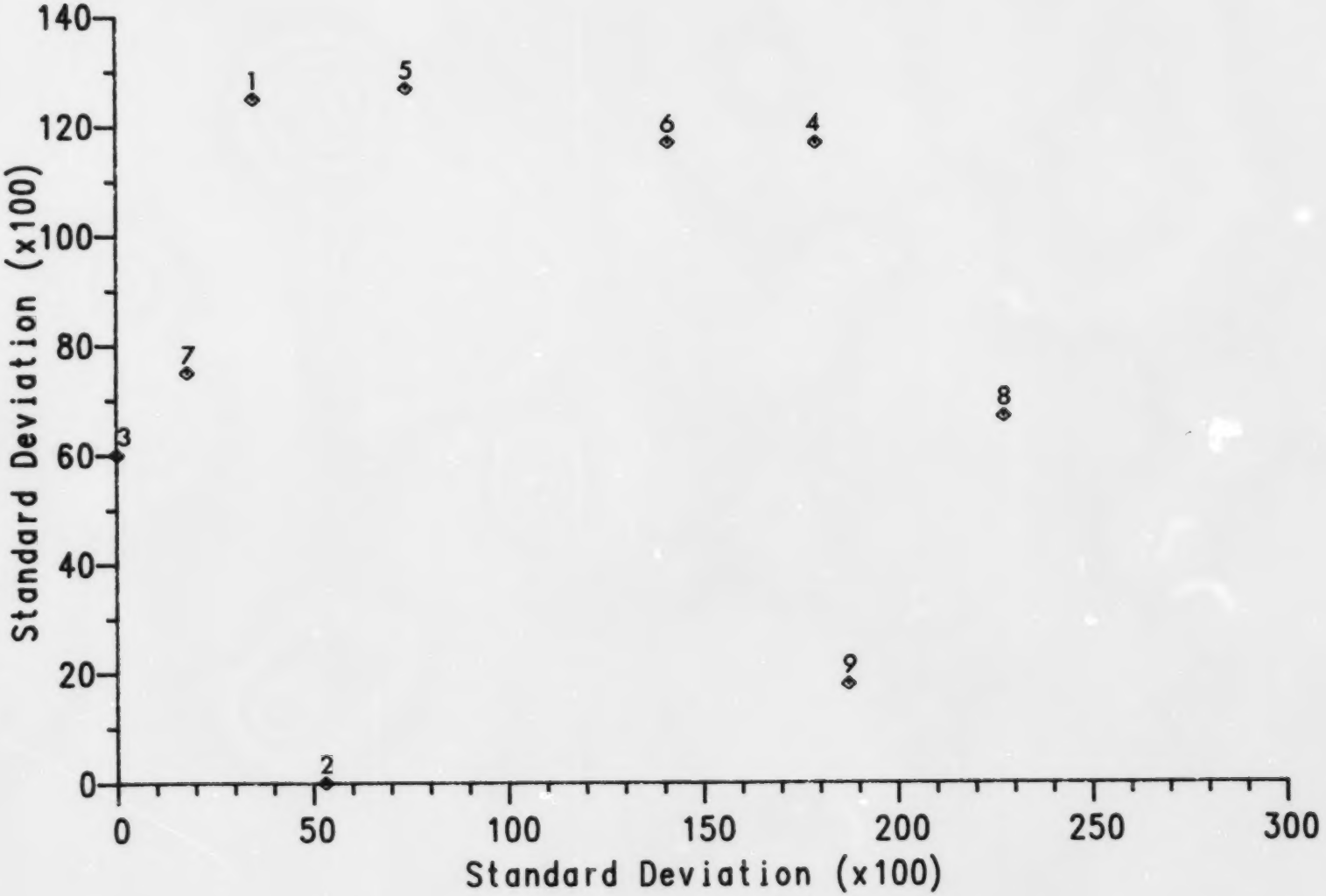

Figure 4: Ordination of Jack Pine Stands Based on Association Values of Understory Vascular Plants, 1982.

grouped in a closer relationship which found sites 4 and 6 to be separated as a pair and sites 1, 3, 5 and 7 to be linked somewhat more tightly. However, within these four a pairing of sites 5 with 7 and 3 with 1 could be identified.

In 1982, the end of the five-year evaluation period, the relationship between similar groups of sites was enhanced (Figure 4). The outliers (sites 2, 8 and 9) remained aloof, however there was considerable change with site 2 dropping to the first axis (horizontal) and sites 8 and 9 drawing closer together. The relationship among the six other sites also reflected a change in vegetation over the five-year period highlighted by an enhancement of sites 4 and 6 as a pair and a regrouping of sites 1 with 5 and 3 with 7. In general, over the five-year period the network of nine study sites drew closer together. The distinct split between sites 8 and 9 and the rest as found in 1977 was not as evident in 1982.

The separation of sites 8 and 9 as distinct from the rest was anticipated since these sites were initially chosen as the control sites for the study network and are located at considerable distance from the other members. These two control sites are also located on a sandy luvisolic soil without a strong shrub component while the other sites are located on brunisolic soils and in general exhibit a well developed shrub stratum. Exceptions were sites 4 and 6 which were also low in shrub cover. In these four sites (8, 9, 4, 6) the herb and bryophyte cover was more strongly developed as a result of the reduced shrub layer.

The change, illustrated in Figure 4 in sites 8 and 9 over the five-year period most likely reflects a change in herb and moss cover. At site 9 there was a considerable increase in herb cover between 1977 and 1982 (46% to 72%) and a slight increase in moss cover (Table 5). At site 8 there was a large decrease in herb cover (147% to 98%) and a substantial increase in moss cover (7% to 34%). The two sites were therefore drawn closer along the second (vertical) axis yet separated by increased variance along the first axis. They still maintained their unique relationship apart from the other six sites.

Site 2, which is uniquely different from the other sites, follows a pattern similar to site 9 when comparing the ordination of 1977 and 1982 along the second axis . However, in terms of the first axis it is situated well away from site 9 and draws a close relationship with sites 1 and 5. The link may be due to the shrub cover; all three sites (1, 2, 5) have only one shrub species, Alnus crispa.

The ordination of sites 4 and 6 reflected a close relationship in both 1977 and 1982. The jack pine in both stands are similar in size and structure and the sites have the lowest percent cover of shrubs. Both sites have a relatively similar cover of vascular plants and experienced a substantial decrease between 1977 and 1982. This decrease in herb cover was accompanied by an approximate 50% increase in moss cover in both sites (Table 5). As a result of these changes the two sites drew closer to the control sites 8 and 9 while maintaining their positions relative to each other.

Table 6: Annual Stack Emission Levels[1]
Inco Ltd., 1977 - 1982

Year	SO_2 (Tonnes)	Particulate (Tonnes)
1977	332,984	2179
1978	214,319	794
1979	206,630	722
1980	218,747	664
1981	153,953	657
1982	127,250	440

1 Inco Monthly Emission Reports submitted to Environmental Control Services Branch, Dept. of Environment and Workplace Safety and Health, Province of Manitoba.

The remaining four sites (1, 3, 5, 7) were somewhat associated in 1977, however, in the 1982 ordination, the pairing of sites 1 with 5 and 3 with 7 occurred. In the 1977 ordination, sites 5 and 7 were likely drawn together initially by their relatively similar stand structure (Table 2) and shrub cover (Table 3). The number of vascular plant species found at sites 1, 5, 7 and 3 were relatively equal in 1977 at 15, 17, 16 and 14 respectively (Table 4), however by 1982, sites 1 and 5 increased to 19 and 20 species while site 7 was reduced to 15 species and site 3 experienced no change at 14. The positive change in species numbers at sites 1 and 5 may have drawn these sites together in the 1982 ordination while the negative change in site 7 may have been responsible for placing that site closer to site 3 in 1982.

As previously stated the pairing of sites 8 and 9 is appropriate in light of their initial selection as control plots. Similarly the pairing of sites 1 with 5, 3 with 7 and 4 with 6 is in keeping with their location in the study network. Although the sites are not ordinated in a position that would reflect their distance from the smelter, they are paired with respect to their relative position on each of the respective transects. That is, sites 1 and 5 are in the first position and 3 and 7 are in the last position of the southwest and southeast transects (Figure 1).

The increase in species numbers at sites 1 and 5 is of interest. As mentioned, these are the two sites located closest to the smelter on each of the southwest and southeast transects. The emission of pollutants from the Inco smelter was considerably reduced

over the period 1978 to 1982 compared with earlier emission levels (Table 6), (Inco Metals Company, 1981). This decrease in emissions would result in a decreased loading on the surrounding environment which, over several years, may have resulted in the improvement of vegetation presence and abundance.

4.2 Black Spruce Sites

4.2.1 Tree Stratum

The black spruce tree inventory data is summarized for 1977 and 1982 in Table 7. The stand ages are more similar for the black spruce sites than for the jack pine. The trees on site 4 were the youngest at 71 years and the second youngest were 75 years old at site 8. The age of remaining sites fell between 80 and 88 years.

An increase in diameter was observed at all locations except site 4. The largest diameter increase in black spruce was found at the control site 9. Diameter growth differences between sites did not appear to be influenced by distance from smelter emissions. Height growth varied between 0.2 to 1.9 m and did not appear to be correlated with distance from the smelter.

The highest percent mortality occurred at sites 1, 3 and 7 while sites 4 and 6 had a very low tree loss. The remaining sites experienced no tree mortality over the five-year period. Basal area increased the most at sites which were not affected by tree mortality as can be expected. Neither tree mortality nor basal area appeared to reflect an association with distance from the smelter.

4.2.2 Shrub Stratum

A summary of shrub data for the black spruce sites is presented in Table 8. No shrubs were found in control sites 8 and 9. Alnus crispa was the dominant species and characteristics of density and cover were fairly consistent over the five-year study.

Table 7: Summary of Tree Data from Black Spruce Biomonitoring Sites, 1977 and 1982

Plot	Tree Species	Mean Diameter (cm)		Mean Height (m)		Mean Age (yrs)		Total Stems Living		Total Stems Dead		Percent Mortality		Basal Area Plot (cm^2)		Total Living Basal Area/Plot (cm^2)	
		1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982
1	Picea mariana	7.87	8.36	13.0	13.4	75	80	62	54	22	8	26.2	12.9	3302.84	3218.38	3323.27	3218.38
	Salix spp.	5.10	-	-	-	-	-	1	-	-	1	-	100.0	20.43	-		
2	Picea mariana	8.35	8.72	12.6	13.1	79	84	36	36	18	-	50.0	0	2485.86	2672.22	2778.47	2981.49
	Betula Papyrifera	8.60	8.80	-	-	-	-	1	1	1	-	-	-	58.09	60.82		
	Pinus banksiana	12.10	12.40	-	-	-	-	2	2	8	-	80.0	0	234.52	248.45		
3	Picea mariana	11.86	12.53	13.9	14.4	79	84	44	38	14	6	24.1	13.6	5304.06	4959.89	5385.19	5100.21
	Populus tremuloides	9.90	12.90	-		-	-	1	1	1	-	50.0	-	76.98	130.70		
	Betula papyrifera	2.30	3.50	-		-	-	1	1	-	-	-	-	4.15	9.62		
4	Picea mariana	7.69	6.26	9.9	11.8	66	71	38	36	2	2	5.0	5.3	1326.17	1371.39	1580.80	1623.89
	Pinus banksiana	12.70	12.65	-	-	-	-	2	2	28	-	93.3	-	254.63	252.50		
5	Picea mariana	5.69	6.03	10.5	11.0	80	85	55	55	-	-	-	-	1616.31	1802.69	1729.41	1923.45
	Larix laricina	12.0	12.40	-	-	-	-	1	1	3	-	75.0	-	113.10	120.76		
	Pinus banksiana	-	-	-	-	-	-	-	-	19	-	100.0	-	-	-		
6	Picea mariana	10.38	10.84	13.2	13.4	83	88	41	40	3	1	6.9	2.4	3812.29	3995.39	4279.72	4501.77
	Populus balsamifera	5.30	5.50	-	-	-	-	1	1	-	-	-	-	22.06	23.76		
	Betula papyrifera	11.70	11.80	-	-	-	-	1	1	-	-	-	-	107.51	109.36		
	Populus tremuloides	14.50	15.25	-	-	-	-	2	2	6	-	85.7	-	337.86	373.26		
7	Picea mariana	13.27	13.58	16.1	16.3	80	85	35	31	5	4	12.5	11.4	5074.94	4685.58	5074.94	4685.58
	Populus tremuloides	-	-	-	-	-	-	-	-	1	-	100.0	-	-	-		
8	Picea mariana	6.89	7.15	10.6	11.8	70	75	99	97	-	-	-	2.02	4405.44	4621.45	4405.44	4621.45
9	Picea mariana	9.87	10.64	12.6	12.9	81	86	20	20	2	-	9.1		1784.51	2014.44	2713.49	2993.79
	Pinus banksiana	12.06	12.36	-	-	-	-	8	8	2	-	20.0	-	928.98	979.35		

Table 8: Summary of Shrub Data from Black Spruce Biomonitoring Sites, 1977 and 1982

Plot	Shrub Species	Mean Height (m)		Mean Crown Width (m)		Mean no. Stems/Shrubs		Total Shrubs/Plot		Total no. Stems/Plot		% Cover		Mean % Mortality/Plot	
		1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982	1977	1982
1	Alnus crispa	0.69	1.17	0.79	0.87	2.7	5.17	10	6	27	31	6.02	4.49	0.00	40.00
	Salix spp.	-	0.70	-	0.40	-	6.00	-	1	-	6	-	0.13	-	0.00
2	Alnus crispa	1.34	1.87	1.14	1.03	8.0	12.00	6	6	48	72	7.19	6.20	0.00	0.00
3	Alnus crispa	1.15	1.10	0.20	0.60	1.0	1.00	1	1	1	1	0.03	0.28	0.00	0.00
4	Salix spp.	3.65	4.00	1.45	1.35	4.0	6.00	2	2	4	12	3.31	2.90	62.5	0.00
5	Alnus crispa	1.52	1.57	0.93	1.19	9.5	16.22	10	9	95	146	8.07	10.96	0.001	10.00
6	Alnus crispa	1.80	2.10	1.37	1.40	3.65	1.00	3	3	11	1	4.55	6.86	0.00	50.00
	Salix spp.	1.13	2.43	1.28	1.70	2.50	5.67	2	1	5	17	3.17	1.54	0.00	0.00
7	Alnus crispa	1.96	2.11	1.29	1.51	4.38	7.25	8	8	35	58	11.20	14.79	0.00	0.00
8	-														
9	-														

The mean number of stems per shrub increased in all sites except 6 where a shift in species from Alnus to Salix appeared to be occurring. The total number of stems per plot increased at all sites with the exception of site 6. At site 6 Alnus density decreased from 11 to 1 stem and Salix increased from 5 to 17.

Mortality was observed in only three sites, 1, 5 and 6, over the five-year study. Mean percent mortality was largest (50%) in site 6 followed by site 1 (40%). Shrub cover decreased at sites 1 and 2 on the southwest transect and increased at the sites on the southeast transect. In general, those sites with a high tree density had fewer numbers of shrubs.

The shrub cover although variable, did not seem to be related to distance from the smelter but rather seemed to reflect site changes. However, in perspective shrub cover is not a major component of the black spruce community; bryophytes dominate the ground cover.

4.2.3 Understory

The data base assembled between 1977 and 1982 for the black spruce has been prepared and presented similar to the jack pine. The composition of the understory is compiled into a frequency-cover index (% cover + % frequency ÷ 2) for each species within each study site. The index values were compiled into an association table or table of species diversity for each year and are found in Appendix B-1 (1977) and B-2 (1982). Specific inventory information for each study site is provided in table format in Appendix D. This includes information on species composition, abundance and values of density, dominance and frequency.

The species distribution can be readily derived from the association tables for both 1977 and 1982. The contribution of vascular plant cover in the black spruce community is not as significant as in the jack pine in terms of ecological development of the sites while the role of cryptogams is more important. Nevertheless the vascular plant cover does contribute to community structure and development.

The understory characteristics of presence, distribution and percent change in association value for both 1977 and 1982 are summarized in Table 9. The number of species increased at most study sites over the five years except for sites 5 and 7 where no change occurred and site 4 where a decrease from 18 to 15 occurred. The study site found to have the greatest increase was site 1 with eight new species. As in the case of the jack pine there did not appear to be a relationship between species number and distance from the smelter. Site 5 is the closest site to the smelter on the southeast transect and was found to have as many species as the control site 8. Site 5 did not show a change in species number over the five-year period. Similarly, species numbers remained constant at site 7 which is furthest from the smelter on the southeast transect.

The percent change in association value between 1977 and 1982 (Table 9) provides an indication of species diversity. A positive change is a desirable change in terms of increased plant diversity as reflected in frequency and cover. The study site showing the largest positive change for black spruce was site 1 (79%) which is closest to the smelter on the southwest transect. There was a positive increase of 50% at sites 2 and 3 (SW transect) while the control site 8 increased by 64%.

Table 9: Summary of Understory Characteristics in Black Spruce, 1977 and 1982

Study Site	No of Species in Understory		% Change in Association Value 1977-1982		
	1977	1982	% Negative	% Positive	% No Change
1	15	23	13	79	8
2	11	12	43	50	7
3	12	15	25	50	25
4	18	15	48	29	23
5	11	11	23	31	46
6	12	16	40	45	15
7	4	4	25	50	25
8	6	11	27	64	9
9	5	6	29	29	42

The location with the lowest percent positive change (29%) and correspondingly the highest negative change (48%) was site 4. For study sites on the southeast transect there was an increase in percent positive change as distance increased away from the smelter (31, 45 and 50 for sites 5, 6 and 7 respectively). Over five years the association values at the control site 9 were quite stable and the percent positive and negative changes were low (29%).

The percent change in association value does not appear to be related to site location or distance from the smelter. Individual site variability appears to be the principle source of change in species abundance at this time.

4.2.4 Bryophytes

Bryophyte distribution did not appear to be influenced by the distance of the sites from the smelter. In 1977, site 3 had the greatest species number with nine while site 5 had the lowest with four species. Species abundance in the remaining sites was fairly similar. An increase in species occurred at site 1 over the five years. The greatest decrease occurred at site 3 where the count dropped from nine to six species. All other plots decreased by one or two species (Appendix B-3 and B-4).

Bryophyte cover for the study plots in the black spruce stands is listed in Table 10. A significant correlation (95%) exists between distance from emission source and bryophyte cover. In both years, bryophyte cover increased as distance from the smelter

Table 10: Summary of Herb and Bryophyte Cover, Black Spruce, 1977 and 1982

Site	% Herb Cover			% Bryophyte Cover			Total	
	1977	1982	%Δ	1977	1982	%Δ	1977	1982
1	81.4	173.9	+113.6	20.3	36.5	+ 79.8	101.7	210.4
2	104.1	106.3	+ 2.1	32.0	55.0	+ 71.9	136.1	161.3
3	18.5	20.7	+ 11.9	86.2	99.2	+ 15.1	104.7	119.9
4	89.6	84.4	- 5.8	15.1	14.1	- 6.6	104.7	98.5
5	131.0	124.2	- 5.2	1.3	29.7	+2184.6	132.3	153.9
6	100.8	80.3	- 20.3	36.6	30.8	- 15.9	137.4	111.1
7	7.2	12.8	+ 77.8	96.7	90.3	+ 6.6	103.9	103.1
8	7.9	5.6	- 29.1	85.4	90.8	+ 6.3	93.3	96.4
9	9.4	8.3	- 11.7	115.0	100.5	- 12.6	124.4	108.8

increased. In 1982 a slight decrease in total percent bryophyte cover was found at sites 4, 6, 7 and 9 as compared to the 1977 assessment. The remaining sites experienced an increase in cover; sites 1, 2 and 5 which are in close proximity to the smelter demonstrated the greatest gain of bryophyte cover. Overall, the increase in moss cover outweighed the small decrease, suggesting a recovery of bryophytes.

The injurious effects of air pollutants on bryophytes is well documented. Bryophytes which lack a cuticle have the ability to absorb and accumulate environmental pollutants. Symptoms of SO_2 injury in mosses begins with chlorosis of exposed leaf tips and this gradually proceeds down until all leaves and shoots lack chlorophyll (Daly, 1970).

Several cases of burnlike symptoms on bryophytes which indicate a chlorophyll loss were observed at sites close to the smelter. During the course of routine field sampling, damage to moss cover was in sufficient evidence that notes on air pollutant symptomalogy were made at each study site for both 1977 and 1982.

Damage symptoms similar to burning were apparent on Pleurozium at site 1 in 1977 but to a considerably smaller degree five years later. Poor condition of mosses was apparent at five microplots at site 2 in 1977 whereas only one microplot showed injury symptoms five years later. Similarly, the slight damage to moss at site 3 in 1977 was not found in 1982. Considerably more injury to bryophytes was found in sites 4 and 5 in 1977 compared to 1982. Six microplots contained injured moss in 1977 whereas four microplots had been

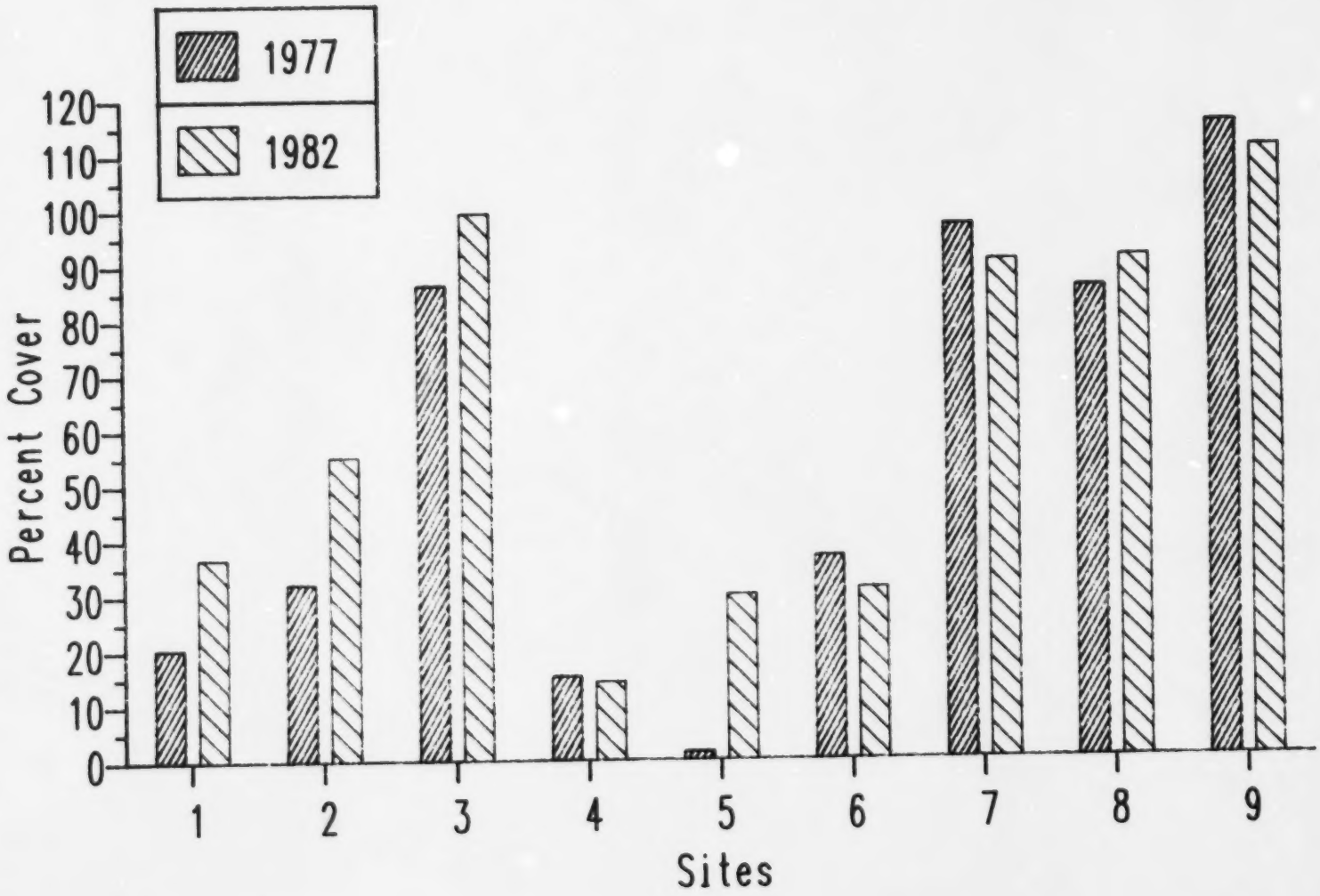

Figure 5: Percent Bryophyte Cover in Black Spruce, 1977–1982.

affected in 1982. Also, site 6 which had some damage symptoms in all microplots in 1977 had only one affected microsite in 1982. Slight injury at site 7 was observed in 1977 but not five years later. In both years, symptoms of air pollution damage to bryophytes was not found at sites 8 and 9.

SO_2 pollution may have contributed to the poor condition of mosses at sites close to the smelter. At other smelter sites, Gilbert (1970), found that short turf and small cushion bryophytes became more luxuriant when SO_2 levels were decreased. General observations from this study indicate that the condition of bryophytes improved over the study duration. A reduction in Inco smelter emissions during the period prior to the 1982 study may account for the favorable response of bryophytes.

4.2.5 Ordination Analysis

Figures 6 and 7 graphically illustrate the ordination of the black spruce vegetation in 1977 and 1982 respectively. The frequency and cover values of vascular plants were used to interpret the relationships found in the jack pine ordination. However, the community components influencing relationships in the black spruce are quite different. Shrubs and subdominant trees are not as common in the black spruce community and the vascular plant component is generally less prominent, while bryophytes notably gain importance and tend to dominate the ground cover. For this reason Table 10 was compiled to assist in the interpretation of the ordination values for black spruce.

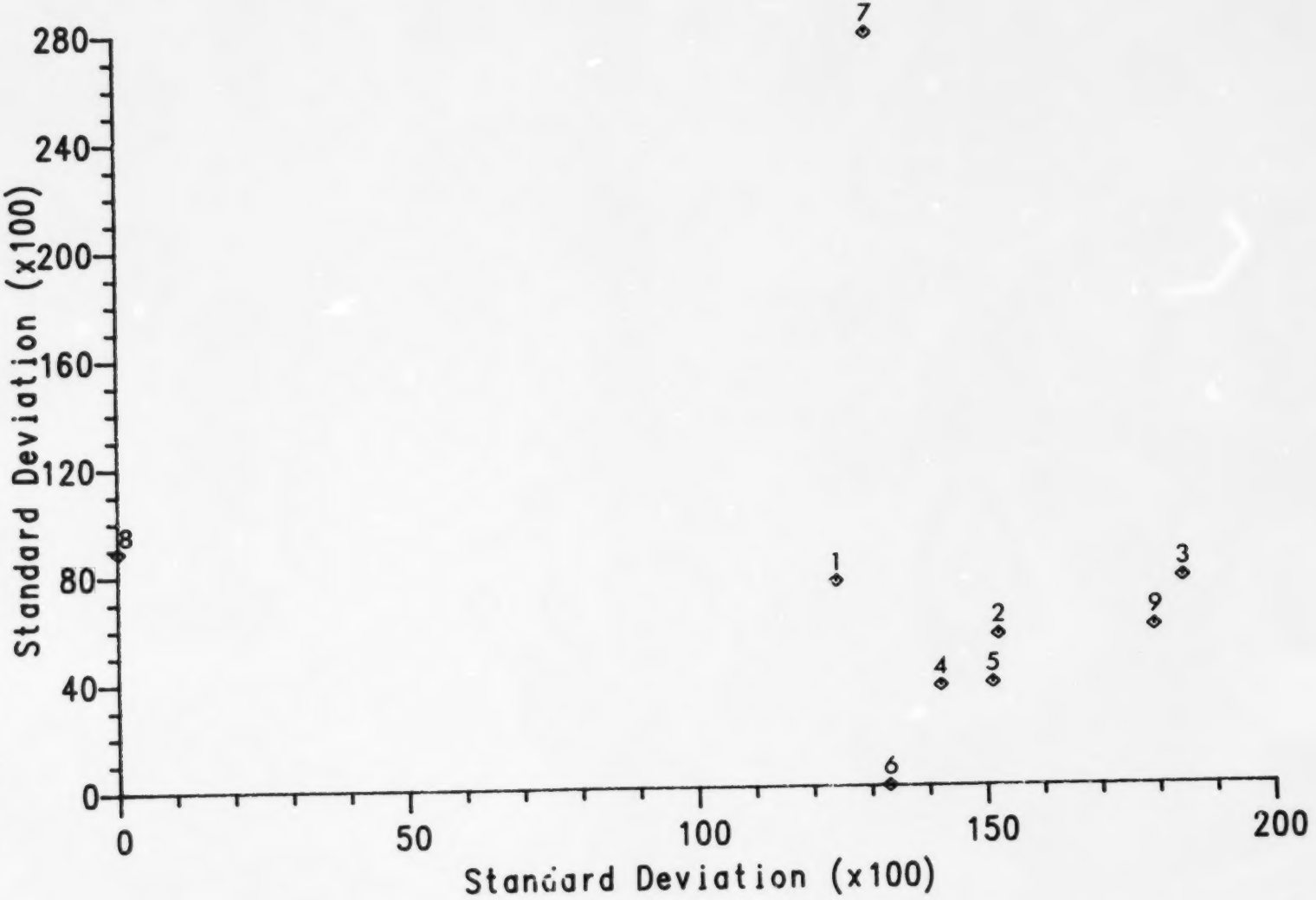

Figure 6: Ordination of Black Spruce Stands Based on Association Values of Understory Vascular Plants, 1977.

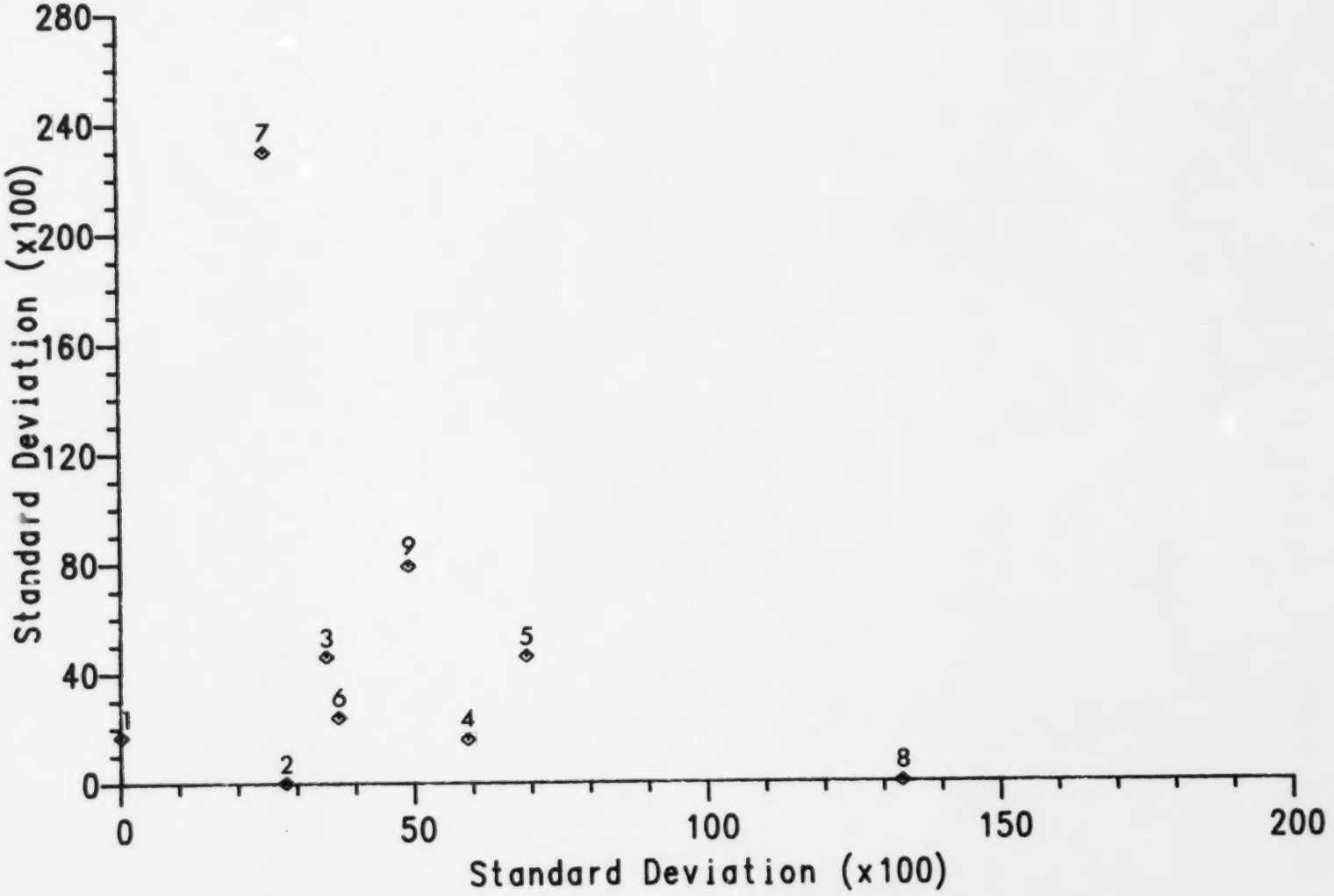

Figure 7: Ordination of Black Spruce Stands Based on Association Values of Understory Vascular Plants, 1982.

The ordination pattern of sites found in the black spruce is not consistent with that of jack pine over the five-year period. In the jack pine, the control sites 8 and 9 are closely linked and separate from other sites. In the black spruce, site 8 is also segregated out, however site 9 forms a close relationship with site 3, which in the regional distribution of sites is closest to site 9. Sites 7 and 8 are outliers in the black spruce ordination in both 1977 and 1982. In 1977, sites 2, 4 and 5 were grouped but were at the same time associated with 1 and 6. This breaks down somewhat in 1982 where sites 4 and 5 maintain a link and 1, 2 and 6 separate out. As an overview, in 1977 sites 3 and 9 were also pulled somewhat away from other sites as was site 1.

A distinct relationship between herb and moss cover is evident in Table 10. Those study sites with highest percent herb cover were found to have the lowest percent moss cover. In comparing the outlier sites 7 and 8 to other sites we find that 7 and 8 had relatively low herb cover and relatively high moss cover. The low herb cover is a reflection of dense crown cover. This is demonstrated by the fact that there were 99 trees in the macroplot at site 8 which is much higher than the overall average of 48 for all nine sites. Although site 7 has less than the average number of stems at 35, the trees are older and the total living basal area is comparable to site 8 (Table 7). In 1982, the spatial relationship of site 7 to the other study sites remained the same due to relative stability in herb and moss cover (Table 9). Site 8 acquired five new herb species in 1982 which likely was responsible for pulling this site closer to those displaying high species number.

Sites 9 and 3 also had a low herb cover and high cover of mosses (Table 10). In 1977 these sites were closer to other sites with relatively high species number than in 1982. During the five-year period percent cover of herbs and mosses declined at site 9 while those at site 3 increased (Table 10). Site 6 experienced a decrease in herb and moss cover in about the same proportion as site 9 which may be the reason for it drawing closer to the 3 and 9 pair in 1982. The link between sites 6 and 3 in 1982 may reflect the increase in species which were common to both sites over the five-year period (Appendix B-6). The number of common species jumped from five to nine by 1982. There was also a close relationship between sites 6 and 2 in 1982. The increase in similarity between sites 6 and 2 in terms of common species was also apparent in 1982. Common species increased from six species in 1977 to nine species in 1982.

The spatial relationship of sites 2, 4, 5 and 6 in 1977 separated out in 1982. This was likely due to the decreasing trends in herb cover which occurred at sites 4, 5 and 6 during the five years. Sites 4 and 5 retained a close association in 1982, although percent cover of bryophytes decreased at site 4 and increased at site 5. However, this did not affect the relative difference in cover between the two sites (Table 10).

The 1982 ordination segregated site 1 from the other sites. In 1977, site 1 was loosely associated with the site grouping 2, 4, 5 and 6 but became more dissimilar in 1982. This may have been caused by the large increase in vascular plant number and cover at site 1

over the five-year period, i.e. 81% to 174% (Table 10). Tree mortality of 13% and shrub mortality of 40% at site 1 would have created a more open canopy to allow the establishment of new species. In addition, reduced smelter emissions over the five-year period would make the establishment of new species more viable.

In general, sites on the southwest transect increased in percent cover of herbs while cover decreased at site 4 south of the smelter and sites 5 and 6 on the southeast transect. The variance between all sites of the study network decreased from approximately 2.9 to 1.34 standard deviations along the first axis over the five-year period; this reflects a movement toward similarity among the nine sites in terms of plant cover.

4.3 Summary Vegetation Analysis

The ordination process allows for comparison of sites within the study network on a relative ecological basis. The process provides a means of quantitatively evaluating vegetation change within the forest ecosystem. Input parameters are frequency and cover of vascular plants and shrubs.

The ordination patterns illustrated in Figures 3, 4, 6 and 7 are not similar. As can be anticipated the jack pine association is distinctly different from the black spruce. The differences are highlighted by the vascular plant community which is more diverse. Vascular cover is of more importance in jack pine as opposed to the black spruce where bryophyte cover is of greater significance.

In this ordination exercise, the jack pine communities appear to be the best indicators of potential anthropogenic effects from the airborne emissions of the Inco Thompson smelter. At the same time the comparison of vegetation change provided by the five-year sampling interval provides opportunity to identify relationships among plots and to quantify positive or negative shifts over the sampling interval. Such shifts can then be traced to various community components for evaluation of probable cause.

In the jack pine ordination the network of nine study sites were found to draw closer together over the five-year period. Initially in 1977 there was a distinct split between the control sites 8 and 9 and the others; this was modified by 1982. In general, jack pine sites maintained consistency in their spatial positions over

the five-year period. Relative site positions in the ordination tended to reflect their physical locations in the study network. Pairing occurred between those closest to the smelter (sites 1, 5) and those further away (sites 3 and 7) with the control sites (8, 9) maintaining separate positions from the others.

In the black spruce, the control site 8 remained segregated over the five-year period, however, site 9 associated with site 3 in 1982. Site 3 was furthest from the smelter on the southwest transect and physically closest to site 9. The ordination of sites in the black spruce network was not as consistent as in the jack pine. Bryophyte cover and vascular cover data base were used to evaluate the relationships found in the ordination. In general, the sites underwent shifts in position over the five-year period, however the separation of sites along the first-axis was consistently within 0.7 standard deviation in both 1977 and 1982, exclusive of the control site. In the 1977 ordination, sites were more tightly clustered and by 1982 sites had drifted apart and tended to show a closer relationship with the control sites. This is consistent with the results of the jack pine ordination.

A variety of biotic and abiotic factors affect the growth and development of forest communities resulting in changes in species composition over time. The successional stage of the stands studied must be considered in order to determine the impact of air pollution on vegetation. Environmental conditions such as light, relative humidity, temperature and available soil moisture will influence the impact of pollutants such as SO_2 (Dreisinger, 1965). Information on heavy metal effects on coniferous vegetation of boreal forests is not

well understood. The complex interaction between accummulation of metals within soil organic horizons and loss of site productivity as well as root-soil toxicity are difficult to interpret and are highly variable.

In this study the influence of airborne emissions of SO_2 and heavy metals from the Inco Thompson smelter did not appear to be affecting tree, shrub or vascular plant growth during the five-year period of study. Although bryophyte distribution did not appear to be influenced by distance from the smelter, there was a positive correlation between bryophyte cover and distance. Bryophyte or moss cover increased with increased distance from the smelter and physical damage symptomatology was readily found in plots close to the smelter. It appears that increase in bryophyte cover over the five-year period may have been the result of decreased emissions from the smelter. This conforms with similar observations of improved conifer foliage found in 1977 at the initiation of the study in comparison to that found three years earlier in 1974 (Hogan et al, 1977). The period 1974 to 1977 was also characterized by reduced smelter emissions.

5. CONCLUSIONS

1. Tree growth measurements over the five-year study period did not appear to be related to distance from the smelter or air pollutant emissions.

2. Shrub density and frequency over the five-year study period did not appear to be correlated with distance from the smelter or to be influenced by air pollutant emissions.

3. The abundance and distribution of understory vascular plants did not appear to be related to distance from the smelter or to be influenced by air pollutants emissions during this five-year study period.

4. Bryophyte cover, although not species distribution, was found to increase as distance increased away from the smelter.

5. Physical damage to bryophytes was found in sampling sites closest to the smelter but was absent at those sites farthest away.

6. Increases in the cover of vascular plant and bryophytes over the five-year period appear to be the result of decreased emissions.

7. Further monitoring and evaluation of bryophyte species with respect to air pollution effects is required in the study area.

8. A five-year monitoring period at reduced levels of air emissions may not be sufficient to distinguish between slow long-term trends and annual or successional variations in both ecological status and air pollution effects on forest growth.

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APPENDIX A

Appendix A-1: Association Table of Understory Species, Jack Pine, 1977

Species	Association Value* by Sample Sites								
	1	2	3	4	5	6	7	8	9
Shrubs									
Alnus crispa	55.40	81.40	63.70		9.18		11.83		
Ledum groenlandicum				8.75	16.80	10.15			
Ribes glandulosum			17.40						
Rosa acicularis	42.95	16.80	42.30	42.30	44.30	44.23	34.26		
Salix spp.								22.56	
Vaccinium myrtilloides				8.75		19.56		62.00	17.40
Shepherdia canadensis				8.75					
Viburnum trilobum	33.90	8.43	17.15		43.23		9.33		
Dwarf Shrubs/Herbs									
Epilobium angustifolium	42.15	8.43	8.58	25.75	34.50	43.68			
Mertensia paniculata	25.80		23.40	54.15	16.90	17.95			
Petasites palmatus	33.90		25.40	25.75		60.41	8.58		
Calamagrostis canadensis	8.43								
Apocynum androsaeifolium			8.92						
Aralia nudicaulis									8.5
Cornus canadensis	62.5	28.4	35.85	72.5	48.15	77.5	71.33	42.3	35.22
Pyrola virens	53.5	43.3	53.5	16.95	25.25	26.0	45.73		
Pyrola secunda	17.0	8.43			17.7		8.58		
Fragaria virginiana	17.3	8.5	60.55	26.75	25.58	43.5	44.06		
Linnaea borealis	58.43	55.08	35.6	64.5	36.1	68.75	48.23	69.0	44.55
Mitella nuda	53.9		30.0	17.65	9.15	27.5	55.31		
Viola pallens	16.8		8.58	33.75	8.5	33.85	16.81		
Arctostaphylos uva-ursi		26.3		39.25	8.43	38.43		34.5	
Moneses uniflora		8.43					8.58		
Galium trifolium				16.75	16.95				
Vaccinium vitis-idaea				59.15	16.75	53.35		79.5	48.4
Geocaulon lividum				45.15			42.48	41.2	33.85
Lathyrus ochroleucus				25.3		8.58			
Maianthemum canadensis						8.58		54.7	
Goodyera repens							8.66		
Potentilla tridentata								40.5	
Smilacina trifolia									39.3
Trientalis borealis									29.3
Carex spp.		8.1							
Pteridophytes									
Lycopodium complanatum	8.43								
Lycopodium lucidium						8.58	8.83		
Equisetum arvense		8.1			8.4	17.9			
Equisetum sylvaticum				16.95			8.58		

* Association Value = $\frac{\% \text{ frequency} + \% \text{ cover}}{2}$

Appendix A-2: Association Table of Understory Species, Jack Pine, 1982

Species	Association Value* by Sample Sites								
	1	2	3	4	5	6	7	8	9
Shrubs									
Alnus crispa	53.33	62.50	82.50		11.25		29.58		40.00
Ledum groenlandicum				8.50	16.92	19.17			
Ribes glandulosum			36.00				8.42		
Rosa acicularis	51.34	16.92	45.00	33.75	46.00	52.00	33.75		
Shepherdia canadensis				8.42					
Vaccinium myrtilloides				34.25		39.25		63.10	17.75
Viburnum trilobum	51.59	8.75	36.34		50.92		19.58		
Dwarf Shrubs/Herbs									
Epilobium angustifolium	33.67	8.42		25.42	42.50	50.75			8.50
Mertensia paniculata			30.42	51.59		33.84			
Petasites palmatus	50.67		33.67	33.67		51.00	8.42		
Aralia nudicaulis									33.75
Aster macrophyllus	34.67								
Aster spp.	8.42				16.83				
Solidago hispida				42.08	8.42	25.25			
Cornus canadensis	66.67	33.00	54.25	58.59	59.84	58.75	62.17	40.80	43.00
Pyrola virens	49.58	26.84	55.84	8.42	25.25	25.42	36.42	10.10	
Pyrola secunda	42.83	26.34	25.25		42.50	8.42	8.42		
Fragaria vesca	42.92			42.42	25.25	42.17		10.10	
Fragaria virginiana	8.42	16.83	63.75	8.50	16.83	35.25			
Linnaea borealis	61.00	52.08	43.42	54.00	53.75	54.67	35.17	55.40	45.33
Mitella nuda	54.84		46.08		10.42	16.92	46.58		
Viola pallens	25.67		25.25	8.42	8.42	16.83	8.42		
Arctostaphylos uva-ursi				28.84	8.42	39.59		41.10	
Galium triflorum				42.08	16.83				
Vaccinium vitis-idaea		36.42		50.84	26.92	59.75		73.50	65.83
Geocaulon lividum				44.08			33.67	52.70	34.42
Lathyrus ochroleucus				16.83		25.34			
Maianthemum canadense									10.10
Goodyera repens			8.42				25.25		
Smilacina trifolia	16.83						8.42	51.40	36.75
Trientalis borealis									25.34
Rubus chamaemorus				16.83					
Caulophyllum thalictroides								30.30	
Calypso bulbosa						16.83			
Carex disperma				52.09	16.83	26.17			8.42
Carex species	8.42							20.20	
Pteridophytes									
Equisetum arvense	8.42					16.83			
Equisetum scirpoides					25.25	8.42			
Equisetum sylvaticum				50.84		33.67			
Lycopodium clavatum							9.17		
Lycopodium complanatum								10.20	
Lycopodium obscurum	9.59								

* Association Value = $\frac{\text{\% frequency + \% cover}}{2}$

Appendix A-3: Percent Bryophyte Cover in Jack Pine Sites, 1977

Species	Percent Cover by Sample Sites								
	1	2	3	4	5	6	7	8	9
Dicranum polysetum		0.17							
Dicranum rugosum		2.50		2.50	2.30	5.50	7.83	2.40	9.30
Dicranum spp.							0.17		
Hylocomium splendens		0.17	0.66	2.50		1.83	7.00		0.17
Hypnum crista-castrensis		0.17	0.17				11.67		
Plagiomnium drummondi			0.33						
Pleurozium schreberi		5.00		10.00		22.50	46.00	4.60	67.30
Pohlia nutans	0.17	0.33	0.50			1.17	0.17		0.17
Polytrichum commune		4.00							0.33
Blepharostoma trichophyllum		0.17							
Ptilidium ciliare	0.17	0.50		0.87	0.50		3.50		
Ptilidium pulcherrimum									0.17
TOTAL SPECIES NO.	2	9	4	4	2	4	7	2	6

Appendix A-4: Percent Bryophyte Cover in the Jack Pine Sites, 1982

	Percent Cover by Sample Sites								
Species	1	2	3	4	5	6	7	8	9
Dicranum fuscescens						0.17			
Dicranum rugosum		14.17		2.00	0.33	3.16	5.83	2.0	3.67
Hylocomium splendens		0.33		17.67	0.17	3.67	3.33		
Hypnum crista castrensis	0.33	0.17	0.33				13.50		
Pleurozium schreberi		20.83		3.17	3.83	54.17	51.67	31.20	75.33
Pohlia nutans	0.17	0.50	0.50		0.17	0.83	0.50	0.50	
Polytrichum commune								0.20	
Unidentified moss			2.67						
Ptilidium ciliare		6.0		4.83	3.17		0.67	0.40	
TOTAL SPECIES NUMBER	2	6	3	4	5	5	6	5	2

Appendix A-5: Number of Common Understory Species Between Sites, Jack Pine, 1977

Site	1	2	3	4	5	6	7	8	9
1									
2	9								
3	12	8							
4	10	7	10						
5	12	11	11	13					
6	10	8	10	15	13				
7	11	9	10	10	10	9			
8	2	3	2	6	4	6	3		
9	2	2	2	5	3	4	3	5	

Appendix A-6: Number of Common Understory Species Between Sites, Jack Pine, 1982

Site	1	2	3	4	5	6	7	8	9
1									
2	9								
3	11	8							
4	9	7	8						
5	13	10	10	14					
6	12	8	10	18	16				
7	12	8	13	8	10	9			
8	6	4	3	8	6	7	5		
9	5	5	3	8	7	6	5	6	

APPENDIX B

Appendix B-1: Association Table of Understory Species, Black Spruce, 1977

Species	Association Value* by Sample Sites								
	1	2	3	4	5	6	7	8	9
Shrubs									
Alnus crispa	40.01								
Ledum groenlandicum	8.68	43.10		15.01	79.6	70.00			
Ribes glandulosum		18.06		8.50					
Rosa acicularis	34.18			25.75	16.80		17.06		
Salix spp.	8.42					18.7			
Vaccinium myrtilloides				16.90	42.56	26.00			34.20
Viburnum trilobum	8.43		8.43	8.50					
Dwarf shrubs/herbs									
Epilobium angustifolium		84.18		8.43	8.43				
Mertensia paniculata			8.50					30.40	
Petasites palmatus	45.23	16.80	8.43	16.80	16.90	55.16			
Actea rubra			8.43						
Vaccinium vitis-idaea		62.06		64.15	85.13	30.00			34.50
Vaccinium oxycoccus		25.40		8.76					
Cornus canadensis	63.00	48.40	28.33	59.50	16.80	44.30	26.00	20.20	25.65
Linnaea borealis	48.43	18.40	34.68	26.50	17.23	44.06	17.15	41.10	8.50
Mitella nuda	56.50		20.06	52.00		45.85		42.10	
Fragaria virginiana	42.40		25.25	25.33					
Gaultheria hispidula		25.91							
Geocaulon lividum					16.80		43.70		
Pyrola virens					8.43	8.50			
Galium triflorum				8.43					
Arctostaphylos rubra	25.25			16.80					
Smilacina trifolia	16.90		8.43						17.0
Goodyera repens			25.33						
Viola pallens	8.43		16.80						
Carex spp.	36.25		16.16	51.90		62.50		10.10	
Pteridophytes									
Equisetum arvense				47.30	25.90	36.26			
Equisetum scirpoides	64.16							12.00	
Equisetum sylvaticum		16.98		25.40		26.50			
Lycopodium sp.		16.08							

* Association Value = $\frac{\% \text{ frequency} + \% \text{ cover}}{2}$

Appendix B-2: Association Table of Understory Species, Black Spruce, 1982

Species	Association Value* by Sample Sites								
	1	2	3	4	5	6	7	8	9
Shrubs									
Alnus crispa	27.25								
Ledum groenlandicum	17.17	53.42		14.17	73.42	69.67			
Ribes glandulosum			8.42						
Rosa acicularis	35.67			42.33	25.42		8.42	20.20	
Salix spp.	10.41								
Vaccinium myrtilloides		8.42	8.42	8.75	42.75	25.67		10.10	35.34
Viburnum trilobum									42.33
Dwarf shrubs/herbs									
Epilobium angustifolium		8.42		16.83				10.10	
Mertensia paniculata	8.42							20.30	
Petasite palmatus	50.84	8.42		16.83	16.83	50.67		10.10	
Actea rubra			8.75						
Solidago hispida			8.42						
Aster spp.			8.42						
Achillea millefolium	25.25								
Vaccinium oxycoccus	8.42	15.84		8.42					
Vaccinium vitis-idaea		75.09		68.75	85.84	26.67		10.10	
Cornus canadensis	66.67	53.42	38.09	51.84	16.83	42.83	35.00	20.20	34.42
Linnaea borealis	54.58	26.75	34.17	17.17	17.08	50.92	16.92	40.40	8.42
Mitella nuda	60.75		19.25	42.25		43.67		30.80	
Fragaria vesca	8.59		8.42	8.42					
Fragaria virginiana	44.50		8.42			8.42			
Geocaulon lividum					25.25	54.42	54.42		
Pyrola secunda	8.42					8.42			
Pyrola virens					8.42	8.42			
Galium triflorum	8.42			8.42	8.42				
Arctostaphylos uva-ursi	25.42			16.83					
Smilacina trifolia	25.84		8.42			8.42			16.92
Goodyera repens			33.75						8.42
Viola pallens	8.42		16.83			8.42			
Rubus chamaemorus		25.84							
Carex disperma	47.50	8.67	8.75			61.50		30.30	
Carex trisperma	27.50								
Pteridophytes									
Equisetum arvense	8.59								
Equisetum scirpoides	79.17	25.59		17.34	16.83	42.58		20.20	
Equisetum sylvaticum	16.83	17.58	8.42	33.67		33.92			

* Association Value = $\frac{\text{\% frequency + \% cover}}{2}$

Appendix B-3: Percent Bryophyte Cover in the Black Spruce, 1977

Species	Percent Cover by Sample Site								
	1	2	3	4	5	6	7	8	9
Aulacomnium palustre	0.83								
Dicranum rugosum			2.67	3.41	0.17	4.83	0.67	0.60	11.80
Dicranum scoparium		3.00							
Hylocomium splendens	0.17		51.17	5.00	0.17	3.33	4.33	53.00	5.30
Hypnum crista-castrensis			11.00			7.50	21.00	2.40	5.10
Plagiomnium drummondi	5.17								
Pleurozium schreberi	3.33		18.67	0.17	0.17	7.50	50.00	28.20	92.50
Pohlia nutans	4.83	0.50	0.50	3.83		1.67		0.20	
Polytrichum commune								0.40	
Polytrichum spp.		0.67							
Sphagnum capillaceum		8.33				1.67			
Unidentified moss #1			0.17						
Unidentified moss #2		0.33							
Blepharostoma trichophyllum	6.00			1.80					
Lepidozia reptans						1.17			
Lophocolea heterophylla			0.17	0.17					
Ptilidium ciliare		19.17	1.33	0.67	0.83	9.50	19.33	0.60	
Ptilidium pulcherrimum			0.50				1.33		0.33
TOTAL SPECIES NUMBER	6	6	9	7	4	8	6	7	5

Appendix B-4: Percent Bryophyte Cover in the Black Spruce, 1982

Species	Percent Cover by Sample Site								
	1	2	3	4	5	6	7	8	9
Aulocomnium palustre						0.33			
Dicranum rugosum	0.67	1.33	5.33	5.83	0.83	4.33	1.00	1.00	3.17
Hylocomium splendens	7.67		63.83	0.17		6.00	4.50	32.20	3.50
Hypnum crista-castrensis	6.33		6.00			8.50	21.33	16.40	
Mnium puncatum	2.50								
Pleurozium schreberi	3.17	0.33	23.00	1.67	0.17	1.00	53.00	39.00	93.50
Pohlia nutans	6.00	2.33	0.50	2.17	1.17	1.83		0.40	
Sphagnum capillaceum		12.50							
Ptilidium ciliare	9.17	38.50	0.50	4.30	27.50	8.83	10.50	1.80	0.33
Scapania undulata	1.00								
TOTAL SPECIES NUMBER	8	5	6	5	4	7	5	6	4

Appendix B-5: Number of Common Understory Species Between Sites, Black Spruce, 1977

Site	1	2	3	4	5	6	7	8	9
1									
2	4								
3	9	3							
4	10	9	7						
5	5	6	3	9					
6	7	6	5	10	8				
7	3	3	2	3	4	2			
8	5	2	5	4	2	4	2		
9	3	3	4	4	4	4	2	2	

Appendix B-6: Number of Common Understory Species Between Sites, Black Spruce, 1982

Site	1	2	3	4	5	6	7	8	9
1									
2	8								
3	9	5							
4	12	10	6						
5	7	7	3	9					
6	12	9	9	9	9				
7	3	2	2	3	4	3			
8	8	8	5	9	7	8	3		
9	3	3	5	3	3	4	2	3	

APPENDIX C

Appendix C-1: Species Composition and Abundance in Jack Pine, Plot 1, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	4.17	69.50	24.17	95.36	66.67	50.00
Viburnum trilobum	1.83	30.50	1.17	4.62	66.67	50.00
Tall Herb						
Epilobium angustifolium	2.16	6.97	1.00	4.29	83.3	29.4
Calamagrostis canadensis	0.33	1.06	0.17	0.73	16.7	5.89
Mertensia paniculata	23.5	75.8	18.3	78.5	33.3	11.8
Petasites palmatus	2.00	6.45	1.17	5.02	66.7	23.5
Rosa acicularis	3.00	9.68	2.67	11.5	83.3	29.4
Low Herb						
Cornus canadensis	42.5	29.0	25.0	42.6	100	19.4
Fragaria virginiana	3.33	2.27	1.33	2.26	33.3	6.45
Linnaea borealis	37.0	25.2	16.3	27.7	100	19.4
Mitella nuda	31.7	21.6	7.80	13.7	100	19.4
Pyrola secunda	2.5	1.70	0.67	1.14	33.3	6.45
Pyrola virens	28.8	19.6	7.00	11.9	100	19.4
Viola pallens	0.83	0.57	0.33	0.56	33.3	6.45
Pteridophytes						
Lycopodium complanatum	0.17	0.12	0.33	0.56	16.7	3.23

Appendix C-2: Species Composition and Abundance in Jack Pine, Plot 2, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa			46.67	99.64	33.33	66.66
Viburnum trilobum	0.17		0.17	0.36	16.67	33.34
Tall Herb						
Epilobium angustifolium	0.33	33.0	0.17	34.0	16.7	33.4
Rosa acicularis	0.67	67.0	0.33	66.0	33.3	66.6
Low Herb						
Arctostaphylos uva-ursi	7.33	13.5	2.67	4.94	50.0	13.6
Carex disperma	0.33	0.61	0.17	0.31	16.7	4.55
Cornus canadensis	11.0	20.3	6.83	12.7	50.0	13.6
Fragaria virginiana	0.83	1.53	0.33	0.61	16.7	4.55
Linnaea borealis	23.3	43.0	10.2	18.9	100	27.3
Moneses uniflora	0.50	0.92	0.17	0.31	16.7	4.55
Pyrola secunda	0.67	1.24	0.17	0.31	16.7	4.55
Pyrola virens	10.0	18.5	3.33	6.17	83.3	22.7
Pteridophytes						
Equisetum arvense	0.17	0.31	0.17	0.31	16.7	4.55

Appendix C-3: Species Composition and Abundance in Jack Pine, Plot 3, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	8.00	90.60	44.17	97.79	83.33	71.43
Viburnum trilobum	0.83	9.40	1.00	2.21	33.33	28.57
Tall Herb						
Apocynum androsaemifolium	1.00	7.59	0.83	4.05	17.0	7.27
Epilobium angustifolium	0.33	2.51	0.17	0.83	17.0	7.27
Mertensia paniculata	3.00	22.8	13.5	65.9	33.3	14.2
Petasites palmatus	4.67	35.5	3.16	15.4	50.0	21.4
Ribes glandulosum	2.00	15.2	1.50	7.32	33.3	14.2
Rosa acicularis	2.17	16.5	1.33	6.49	83.3	35.6
Low Herbs						
Cornus canadensis	7.50	8.16	5.00	10.4	66.7	16.7
Fragaria virginiana	23.3	25.4	21.2	44.3	100	25.0
Linnaea borealis	7.0	7.61	4.50	9.40	66.7	16.7
Mitella nuda	36.5	39.7	10.0	20.9	50.0	12.5
Pyrola virens	16.8	18.3	7.00	14.6	100	25.0
Viola pallens	0.83	0.90	0.17	0.36	17.0	4.25

Appendix C-4: Species Composition and Abundance in Jack Pine, Plot 4, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herbs						
Epilobium angustifolium	1.83	10.3	1.50	10.2	50.0	15.0
Ledum groenlandicum	0.83	4.66	0.83	5.67	16.7	5.01
Mertensia paniculata	8.33	46.8	8.33	56.9	100	30.0
Petasites palmatus	2.67	15.0	1.50	10.2	50.0	15.0
Rosa acicularis	2.83	15.9	1.33	9.08	83.3	25.0
Shepherdia canadensis	0.50	2.81	0.33	2.25	16.7	5.01
Vaccinium myrtilloides	0.83	4.66	0.83	5.67	16.7	5.01
Low Herb						
Arctostaphylos uva-ursi	17.7	6.17	11.8	8.60	66.7	9.10
Cornus canadensis	88.3	30.8	45.0	32.8	100	13.6
Fragaria virginiana	6.00	2.09	3.50	2.55	50.0	6.82
Galium triflorum	1.83	0.64	0.87	0.63	33.3	4.54
Geocaulon lividum	15.7	5.47	7.00	5.10	83.3	11.4
Lathyrus ochroleucus	1.67	0.58	0.67	0.49	50.0	6.82
Linnaea borealis	68.2	23.8	29.0	21.1	100	13.6
Mitella nuda	7.00	2.44	2.00	1.46	33.3	4.54
Pyrola virens	1.17	0.41	0.67	0.49	33.3	4.54
Vaccinium vitis - idaea	76.0	26.5	35.2	25.7	83.3	11.4
Viola pallens	2.67	0.93	0.83	0.60	66.7	9.10
Pteridophytes						
Equisetum sylvaticum	0.67	0.23	0.67	0.49	33.3	4.54

Appendix C-5: Species Composition and Abundance in Jack Pine, Plot 5, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	0.17	9.24	1.67	58.80	16.67	16.67
Viburnum trilobum	1.67	90.76	1.17	41.20	83.33	83.33
Tall Herb						
Epilobium angustifolium	2.83	24.6	2.33	27.5	66.7	30.8
Ledum groenlandicum	0.50	4.35	0.33	3.90	33.3	15.4
Mertensia paniculata	1.17	10.2	0.50	5.91	33.3	15.4
Rosa acicularis	7.00	60.9	5.33	63.0	83.3	38.5
Low Herb						
Arctostaphylos uva ursi	0.17	0.37	0.17	0.63	16.7	4.01
Cornus canadensis	17.3	37.5	13.0	48.2	83.3	20.0
Fragaria virginiana	2.83	6.14	1.17	4.33	50.0	12.0
Galium triflorum	1.83	3.97	0.30	1.11	33.3	7.99
Linnaea borealis	9.33	20.2	5.50	20.4	66.7	16.0
Mitella nuda	3.50	7.59	1.67	6.19	16.7	4.01
Pyrola secunda	5.00	10.9	2.17	8.04	33.3	7.99
Pyrola virens	1.17	2.54	0.50	1.85	50.0	12.0
Vaccinium vitis -idaea	4.17	9.05	2.00	7.41	33.3	7.99
Viola pallens	0.67	1.45	0.33	1.22	16.7	4.01
Pterodophytes						
Equisetum arvense	0.17	0.37	0.17	0.63	16.7	4.01

Appendix C-6: Species Composition and Abundance in Jack Pine, Plot 6, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Epilobium angustifolium	4.33	10.6	4.17	9.94	83.3	23.8
Ledum groenlandicum	0.83	2.03	3.33	7.93	17.0	4.85
Mertensia paniculata	2.67	6.52	2.67	6.36	33.3	9.51
Petasites palmatus	19.8	48.3	20.8	49.6	100	28.6
Rosa acicularis	5.00	12.2	5.17	12.3	83.3	23.8
Vaccinium myrtilloides	8.33	20.3	5.83	13.9	33.3	9.51
Low Herb						
Arctostaphylos uva-ursi	12.3	4.78	10.2	6.58	66.7	10.5
Cornus canadensis	76.0	29.6	55.0	35.5	100	15.8
Fragaria virginiana	4.83	1.88	3.83	2.47	83.3	13.1
Lathyrus ochroleucus	0.33	0.13	0.17	0.11	17.0	2.68
Linnaea borealis	56.0	21.8	37.5	24.7	100	15.8
Maianthemum canadense	0.66	0.26	0.17	0.11	17.0	2.68
Mitella nuda	11.3	4.40	5.0	3.22	50.0	7.88
Pyrola virens	3.67	1.42	2.0	1.29	50.0	7.88
Vaccinium vitis - idaea	88.8	34.5	40.0	25.8	66.7	10.5
Viola pallens	2.67	1.04	1.0	0.64	66.7	10.5
Pteridophytes						
Lycopodium lucidulum	0.50	0.19	0.17	0.11	17.0	2.68

Appendix C-7: Species Composition and Abundance in Jack Pine, Plot 7, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	2.17	72.33	6.67	79.98	16.67	50.00
Viburnum trilobum	0.83	27.67	1.67	20.02	16.67	50.00
Tall Herb						
Petasites palmatus	0.17	7.26	0.17	8.50	17.0	20.3
Rosa acicularis	2.17	92.7	1.83	91.5	66.7	79.7
Low Herb						
Cornus canadensis	54.8	29.5	42.7	42.8	100	15.8
Fragaria virginiana	5.00	2.70	4.83	4.84	83.3	13.1
Geocaulon lividum	2.17	1.17	1.67	1.68	83.3	13.1
Goodyera repens	0.83	0.45	0.33	0.33	17.0	2.68
Linnaea borealis	20.7	11.2	13.2	13.2	83.3	13.1
Mitella nuda	87.3	47.1	27.3	27.4	83.3	13.1
Moneses uniflora	0.17	0.09	0.17	0.17	17.0	2.68
Pyrola secunda	0.33	0.18	0.17	0.17	17.0	2.68
Pyrola virens	12.7	6.85	8.17	8.19	83.3	13.1
Viola pallens	0.50	0.27	0.33	0.33	33.3	5.25
Pteridophytes						
Equisetum sylvaticum	0.17	0.09	0.17	0.17	17.0	2.68
Lycopodium lucidulum	0.83	0.45	0.66	0.66	17.0	2.68

Appendix C-8: Species Composition and Abundance in Jack Pine, Plot 8, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Vaccinium myrtilloides	17.2	100	24.0	100	100	100
Low Herb						
Arctostaphylos uva-ursi	9.60	7.20	9.00	7.29	60.0	10.0
Cornus canadensis	7.00	5.25	4.60	3.73	80.0	13.3
Geocaulon lividum	7.40	5.55	2.40	1.94	80.0	13.3
Linnaea borealis	14.4	10.8	38.0	30.8	100	16.7
Maianthemum canadense	13.8	10.3	9.40	7.62	100	16.7
Potentilla tridentata	1.20	0.90	1.00	0.81	80.0	13.3
Vaccinium vitis - idaea	80.0	60.0	59.0	47.8	100	16.7

Appendix C-9: Species Composition and Abundance in Jack Pine, Plot 9, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Vaccinium myrtilloides	1.50	100	1.50	100	33.3	100
Low Herb						
Cornus canadensis	5.50	3.48	3.75	8.43	66.7	16.0
Geocaulon lividum	1.67	1.06	1.00	2.25	66.7	16.0
Linnaea borealis	17.3	10.9	5.80	13.0	83.3	20.0
Smilacina trifolia	21.5	13.6	11.9	26.7	66.7	16.0
Trientalis borealis	5.17	3.27	8.60	19.3	50.0	12.0
Vaccinium vitis - idaea	112	70.9	13.4	30.1	83.3	20.0

Appendix C-10: Species Composition and Abundance in Jack Pine, Plot 1, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	3.67	53.65	23.33	88.04	83.33	45.55
Viburnum trilobum	3.17	46.35	3.17	11.96	100.00	54.55
Tall Herb						
Aster macrophyllus	21.00	71.60	19.33	79.98	50.00	15.00
Aster sp.	0.50	1.69	0.17	0.70	16.67	5.00
Epilobium angustifolium	1.00	3.41	0.67	2.77	66.67	20.00
Petasites palmatus	3.33	11.35	1.33	5.50	100.00	30.00
Rosa acicularis	3.50	11.93	2.67	11.05	100.00	30.00
Low Herb						
Carex spp.			0.17	0.19	16.67	2.38
Cornus canadensis	59.17	28.72	33.33	36.90	100.00	14.29
Fragaria vesca	4.50	2.18	2.50	2.77	83.33	11.90
Fragaria virginiana	0.17	0.08	0.17	0.19	16.67	2.38
Linnaea borealis	56.83	27.59	22.00	24.36	100.00	14.29
Mitella nuda	45.83	22.25	9.67	10.71	100.00	14.29
Pyrola secunda	5.83	2.83	2.33	2.58	83.33	11.90
Pyrola virens	25.50	12.38	15.83	17.52	83.33	11.90
Smilacina trifolia	1.00	0.49	0.33	0.37	33.33	4.76
Viola pallens	3.67	1.78	1.33	1.47	50.00	7.14
Pteridophytes						
Equisetum arvense	0.17	0.08	0.17	0.19	16.67	2.38
Lycopodium obscurum	3.33	1.62	2.50	2.77	16.67	2.38

Appendix C-11: Species Composition and Abundance in Jack Pine, Plot 2, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	10.00	90.91	41.67	98.05	83.33	83.33
Viburnum trilobum	1.00	9.09	0.83	1.95	16.67	16.67
Tall Herb						
Epilobium angustifolium	0.17	12.69	0.17	25.37	16.67	33.34
Rosa acicularis	1.17	87.31	0.50	74.63	33.33	66.66
Low Herb						
Cornus canadensis	24.33	19.39	11.00	24.63	50.00	15.00
Fragaria virginiana	0.83	0.66	0.33	0.74	33.33	10.00
Linnaea borealis	63.83	50.86	20.83	46.63	83.33	25.00
Pyrola secunda	7.50	5.98	2.67	5.98	50.00	15.00
Pyrola virens	8.67	6.91	3.67	8.22	50.00	15.00
Vaccinium vitis - idaea	20.33	16.20	6.17	13.81	66.67	20.00

Appendix C-12: Species Composition and Abundance in Jack Pine, Plot 3, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	10.33	79.10	81.67	93.16	100.00	50.00
Viburnum trilobum	2.83	20.90	6.00	6.84	66.67	40.00
Tall Herb						
Mertensia paniculata	13.83	56.08	10.83	46.09	50.00	18.75
Petasites palmatus	1.50	6.08	0.67	2.85	66.67	25.00
Ribes glandulosum	4.00	16.22	5.33	22.68	66.67	25.00
Rosa acicularis	5.33	21.61	6.67	28.38	83.33	31.25
Low Herb						
Cornus canadensis	17.50	12.59	8.50	13.90	100.00	17.14
Fragaria virginiana	33.33	23.98	27.50	44.96	100.00	17.14
Goodyera repens	0.33	0.24	0.17	0.28	16.67	2.86
Linnaea borealis	11.67	8.40	3.50	5.72	83.33	14.29
Mitella nuda	47.00	33.81	8.83	14.43	83.33	14.29
Pyrola secunda	1.83	1.32	0.50	0.82	50.00	8.57
Pyrola virens	25.67	18.47	11.67	19.08	100.00	17.14
Viola pallens	1.67	1.20	0.50	0.82	50.00	8.57

Appendix C-13: Species Composition and Abundance in Jack Pine, Plot 4, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Epilobium angustifolium	2.00	4.41	0.83	9.23	50.00	10.31
Ledum groenlandicum	0.67	1.48	0.33	3.67	16.67	3.44
Mertensia paniculata	18.67	41.17	3.17	35.26	100.00	20.62
Petasites palmatus	2.00	4.41	0.67	7.45	66.67	13.75
Rosa acicularis	2.17	4.79	0.83	9.23	66.67	13.75
Rubus chamaemorus	3.50	7.72	0.33	3.67	33.33	6.87
Shepherdia canadensis	0.17	0.37	0.17	1.89	16.67	3.44
Solidago hispida	1.67	3.68	0.83	9.23	83.33	17.18
Vaccinium myrtilloides	14.50	31.97	1.83	20.36	66.67	13.75
Low Herb						
Arctostaphylos uva-ursi	23.67	5.14	7.67	9.37	50.00	5.88
Caredisperma	17.50	3.80	4.17	5.10	100.00	11.76
Cornus canadensis	96.83	21.01	17.17	20.98	100.00	11.76
Fragaria vesca	4.17	0.91	1.50	1.83	83.33	9.80
Fragaria virginiana	1.50	0.33	0.33	0.40	16.67	1.96
Galium triflorum	3.50	0.76	0.83	1.01	83.33	9.80
Geocaulon lividum	26.50	5.75	4.83	5.90	83.33	9.80
Lathyrus ochroleucus	1.17	0.25	0.33	0.40	33.33	3.92
Linnaea borealis	90.67	19.67	8.00	9.78	100.00	11.76
Pyrola virens	0.83	0.18	0.17	0.21	16.67	1.96
Vaccinium vitis-idaea	189.17	41.05	35.00	42.77	66.67	7.84
Viola pallens	0.33	0.07	0.17	0.21	16.67	1.96
Pteridophytes						
Equisetum sylvaticum	5.00	1.08	1.67	2.04	100.00	11.76

Appendix C-14: Species Composition and Abundance in Jack Pine, Plot 5, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	0.83	22.68	5.83	76.11	16.67	14.29
Viburnum trilobum	2.83	77.32	1.83	23.89	100.00	85.71
Tall Herb						
Aster sp.	1.17	9.48	0.33	2.91	33.33	13.33
Epilobium angustifolium	2.50	20.26	1.67	14.73	83.33	33.33
Ledum groenlandicum	1.00	8.10	0.50	4.41	33.33	13.33
Rosa acicularis	7.50	60.78	8.67	76.46	83.33	33.33
Solidago hispida	0.17	1.38	0.17	1.50	16.67	6.67
Low Herb						
Arctostaphylos uva-ursi	0.17	0.15	0.17	0.43	16.67	2.77
Carex disperma	0.67	0.60	0.33	0.83	33.33	5.54
Cornus canadensis	45.83	41.34	19.67	49.58	100.00	16.62
Fragaria vesca	2.83	2.55	0.50	1.26	50.00	8.31
Fragaria virginiana	1.17	1.06	0.33	0.83	16.67	2.77
Galium triflorum	1.50	1.35	0.33	0.83	33.33	5.54
Linnaea borealis	20.33	18.34	7.50	18.91	100.00	16.62
Mitella nuda	14.50	13.08	4.17	10.51	16.67	2.77
Pyrola secunda	7.67	6.92	1.67	4.21	83.33	13.85
Pyrola virens	1.17	1.06	0.50	1.26	50.00	8.31
Vaccinium vitis-idaea	14.17	12.78	3.83	9.65	50.00	8.31
Viola pallens	0.17	0.15	0.17	0.43	16.67	2.77
Pteridophytes						
Equisetum scirpoides	0.67	0.60	0.50	1.26	50.00	8.31

Appendix C-15: Species Composition and Abundance in Jack Pine, Plot 6, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Epilobium angustifolium	3.83	8.15	1.50	5.81	100.00	19.36
Ledum groenlandicum	1.50	3.19	5.00	19.36	33.33	6.45
Mertensia paniculata	4.00	8.51	1.00	3.87	66.67	12.90
Petasites palmatus	13.17	28.02	2.00	7.74	100.00	19.36
Rosa acicularis	8.33	17.72	4.00	15.49	100.00	19.36
Solidago hispida	0.50	1.06	0.50	1.94	50.00	9.68
Vaccinium myrtilloides	15.67	33.34	11.83	45.80	66.67	12.90
Low Herb						
Arctostaphylos uva-ursi	27.00	6.66	12.50	15.03	66.67	7.84
Calypso bulbosa	2.67	0.66	0.33	0.40	33.33	3.92
Carex disperma	7.00	1.73	2.33	2.80	50.00	5.88
Cornus canadensis	82.83	20.52	17.50	21.04	100.00	11.76
Fragaria vesca	5.50	1.36	1.00	1.20	83.33	9.80
Fragaria virginiana	0.67	0.17	0.33	0.40	33.33	3.92
Lathyrus ochroleucus	1.17	0.29	0.67	0.81	50.00	5.88
Linnaea borealis	84.33	20.79	9.33	11.22	100.00	11.76
Mitella nuda	9.50	2.34	0.50	0.60	33.33	3.92
Pyrola secunda	0.33	0.08	0.17	0.20	16.67	1.96
Pyrola virens	4.00	0.99	0.83	1.00	50.00	5.88
Vaccinium vitis-idaea	178.83	44.08	36.17	43.49	83.33	9.80
Viola pallens	0.67	0.17	0.33	0.40	33.33	3.92
Pteridophytes						
Equisetum arvense	0.67	0.17	0.33	0.40	33.33	3.92
Equisetum sylvaticum	3.33	0.82	0.67	0.81	66.67	7.84
Equisetum scirpoides	0.17	0.04	0.17	0.20	16.67	1.96

Appendix C-16: Species Composition and Abundance in Jack Pine, Plot 7, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	5.17	58.48	25.83	81.59	33.33	50.00
Viburnum trilobum	3.67	41.52	5.83	18.41	33.33	50.00
Tall Herb						
Petasites palmatus	0.67	26.80	0.17	14.53	16.67	16.67
Ribes glandulosum	0.16	6.40	0.17	14.53	16.67	16.67
Rosa acicularis	1.67	66.80	0.83	70.94	66.67	66.67
Low Herb						
Cornus canadensis	70.17	30.64	24.33	47.54	100.00	17.65
Fragaria virginiana	8.67	3.79	3.83	7.48	66.67	11.76
Geocaulon lividum	1.33	0.58	0.67	1.31	66.67	11.76
Goodyera repens	2.00	0.87	0.50	0.98	50.00	8.82
Linnaea borealis	28.33	12.37	3.67	7.17	66.67	11.76
Mitella nuda	87.67	38.28	9.83	19.21	83.33	14.70
Pyrola secunda	0.17	0.07	0.17	0.33	16.67	2.94
Pyrola virens	24.67	10.77	6.17	12.06	66.67	11.76
Smilacina trifolia	0.50	0.22	0.17	0.33	16.67	2.94
Viola pallens	0.33	0.14	0.17	0.33	16.67	2.94
Pteridophytes						
Lycopodium clavatum	5.17	2.26	1.67	3.26	16.67	2.94

Appendix C-17: Species Composition and Abundance in Jack Pine, Plot 8, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Vaccinium myrtilloides	43.20	100.00	26.20	100.00	100.00	100.00
Low Herb						
Arctostaphylos uva-ursi	9.60	2.08	2.20	3.07	80.00	11.11
Carex spp.	0.40	0.09	0.40	0.56	40.00	5.56
Caulophyllum thalictroides	1.80	0.39	0.60	0.84	60.00	8.33
Cornus canadensis	7.80	1.69	1.60	2.23	80.00	11.11
Fragaria vesca	0.20	0.04	0.20	0.28	20.00	2.78
Linnaea borealis	122.20	26.52	10.80	15.08	100.00	13.89
Pyrola virens	1.40	0.30	0.20	0.28	20.00	2.78
Smilacina trifolia	16.40	3.56	2.80	3.91	100.00	13.89
Vaccinium vitis-idaea	277.20	60.16	47.00	65.64	100.00	13.89
Pteridophytes						
Lycopodium complanatum	1.00	0.22	0.40	0.56	20.00	2.78

Appendix C-18: Species Composition and Abundance in Jack Pine, Plot 9, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	3.83	100.00	30.00	100.00	50.00	100.00
Tall Herb						
Aralia nudicaulis	0.67	15.44	0.83	24.92	66.67	57.14
Epilobium angustifolium	0.50	11.52	0.33	9.91	16.67	14.29
Vaccinium myrtilloides	3.17	73.04	2.17	66.17	33.33	28.57
Low Herb						
Carex disperma	1.17	0.37	0.17	0.25	16.67	3.70
Cornus canadensis	8.00	2.54	2.67	3.92	83.33	18.52
Geocaulon lividum	7.83	2.48	2.17	3.18	66.67	14.82
Linnaea borealis	34.67	11.00	7.33	10.75	83.33	18.52
Smilacina trifolia	22.17	7.03	6.83	10.02	66.67	14.82
Trientalis borealis	2.67	0.85	0.67	0.98	50.00	11.11
Vaccinium vitis-idaea	238.67	75.72	48.33	70.90	83.33	18.52

APPENDIX D

Appendix D-1: Species Composition and Abundance in Black Spruce, Plot 1, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	1.83	73.49	13.33	71.44	66.67	66.67
Salix spp.	0.33	13.25	5.00	26.80	16.67	16.67
Viburnum trilobum	0.33	13.25	0.33	1.77	16.67	16.67
Tall Herb						
Ledum groenlandicum	0.83	5.41	0.67	7.05	16.7	10.0
Petasites palmatus	13.0	84.8	7.17	75.4	83.3	49.9
Rosa acicularis	1.50	9.78	1.67	17.6	66.7	39.9
Low Herb						
Arctostaphylos rubra	1.33	1.16	0.50	0.70	50.0	11.1
Cornus canadensis	40.0	34.8	26.0	36.2	100.	22.2
Fragaria virginiana	3.67	3.19	1.50	2.10	83.3	18.5
Linnaea borealis	20.7	18.0	30.2	42.0	66.7	14.8
Mitella nuda	47.5	41.3	13.0	18.1	100.0	22.2
Smilacina trifolia	1.33	1.16	0.50	0.70	33.3	7.40
Vaccinium vitis-idaea	0.17	0.15	0.17	0.24	16.7	3.71

Appendix D-2: Species Composition and Abundance in Black Spruce, Plot 2, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Epilobium angustifolium	0.50	2.35	1.67	6.87	100.0	42.9
Ledum groenlandicum	18.8	88.3	19.5	80.2	66.7	28.6
Petasites palmatus	0.67	3.15	0.33	1.36	33.3	14.3
Ribes glandulosum	1.33	6.24	2.83	11.6	33.3	14.3
Low Herb						
Cornus canadensis	20.5	9.72	13.5	16.9	83.3	26.3
Gaultheria hispidula	4.67	2.21	1.83	2.29	50.0	15.8
Linnaea borealis	5.83	2.76	3.50	4.39	33.3	10.5
Vaccinium oxycoccus	41.7	19.8	17.5	21.9	33.3	10.5
Vaccinium vitis-idaea	137.0	64.9	40.8	51.1	83.3	26.3
Pteridophytes						
Equisetum sylvaticum	1.50	0.71	2.67	3.35	33.3	10.5

Appendix D-3: Species Composition and Abundance in Black Spruce, Plot 3, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Viburnum trilobum	0.17	100.00	0.17	100.00	16.67	100.00
Tall Herb						
Actaea rubra	0.17	14.5	0.17	25.4	16.7	33.3
Mertensia paniculata	0.67	57.3	0.33	49.3	16.7	33.3
Petasites palmatus	0.33	28.2	0.17	25.4	16.7	33.3
Low Herb						
Cornus canadensis	16.3	34.1	6.67	37.5	50.0	16.7
Fragaria virginiana	1.00	2.09	0.50	2.81	50.0	16.7
Goodyera repens	5.50	11.5	0.67	3.76	50.0	16.7
Linnaea borealis	6.67	14.0	2.67	15.0	66.7	22.2
Mitella nuda	17.5	36.6	6.83	38.4	33.3	11.1
Smilacina trifolia	0.17	0.36	0.17	0.96	16.7	5.57
Viola pallens	0.67	1.40	0.33	1.85	33.3	11.1

Appendix D-4: Species Composition and Abundance in Black Spruce, Plot 4, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Viburnum trilobum	0.17	100.00	0.33	100.00	16.67	100.00
Tall Herb						
Epilobium angustifolium	0.33	3.88	0.17	1.08	16.7	12.6
Ledum groenlandicum	4.33	50.9	13.3	84.2	16.7	12.6
Ribes glandulosum	0.17	2.00	0.33	2.09	16.7	12.6
Rosa acicularis	2.50	29.4	1 50	9.49	50.0	37.6
Vaccinum myrtilloides	1.17	13.8	0.50	3.16	33.3	25.0
Low Herb						
Arctostaphylos rubra	0.67	0.44	0.33	0.45	33.3	6.66
Cornus canadensis	34.3	22.7	19.0	25.7	100.0	20.0
Fragaria virginiana	2.50	1.66	0.67	0.91	50.0	10.0
Galium trifolium	1.00	0.66	0.17	0.23	16.7	3.34
Linnaea borealis	9.50	6.29	3.00	4.07	50.0	10.0
Mitella nuda	15.3	10.1	4.00	5.42	100.0	20.0
Vaccinium oxycoccus	7.33	4.85	0.83	1.12	16.7	3.34
Vaccinium vitis-idaea	78.8	52.2	45.0	61.0	83.3	16.7
Pteridophytes						
Equisetum sylvaticum	1.17	0.77	0.83	1.12	50.0	10.0

Appendix D-5: Species Composition and Abundance in Black Spruce, Plot 5, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Epilobium angustifolium	0.17	0.65	0.17	0.27	16.7	6.25
Ledum groenlandicum	19.8	75.9	59.2	95.5	100.0	37.5
Petasites palmatus	0.67	2.57	0.50	0.81	33.3	12.5
Rosa acicularis	1.33	5.10	0.33	0.53	33.3	12.5
Vaccinium myrtilloides	4.17	16.0	1.83	2.95	83.3	31.2
Low Herb						
Cornus canadensis	1.00	0.55	0.33	0.48	33.3	15.3
Geocaulon lividum	0.83	0.46	0.33	0.48	33.3	15.3
Linnaea borealis	4.00	2.20	1.17	1.70	33.3	15.3
Pyrola virens	0.33	0.18	0.17	0.25	16.7	7.70
Vaccinium vitis-idaea	176.00	96.7	66.7	96.7	100.0	46.1

Appendix D 6: Species Composition and Abundance in Black Spruce, Plot 6, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Ledum groenlandicum	16.2	52.8	40.0	76.5	100.0	40.0
Petasites palmatus	10.3	33.6	10.3	19.7	100.0	40.0
Vaccinium myrtilloides	4.17	13.6	2.00	3.82	50.0	20.0
Low Herb						
Cornus canadensis	7.00	8.51	5.33	11.0	83.3	23.8
Linnaea borealis	8.83	10.7	4.83	9.96	83.3	23.8
Mitella nuda	44.8	54.4	25.0	51.5	66.7	19.1
Pyrola virens	1.00	1.22	0.33	0.68	16.7	4.77
Vaccinium vitis-idaea	19.2	23.3	10.0	20.6	50.0	14.3
Pteridophytes						
Equisetum sylvaticum	1.50	1.82	3.00	6.19	50.0	14.3

Appendix D-7: Species Composition and Abundance in Black Spruce, Plot 7, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Low Herb						
Cornus canadensis	3.33	29.0	2.00	27.9	50.0	29.9
Geocaulon lividum	5.67	49.3	4.17	58.2	83.3	49.9
Linnaea borealis	2.50	21.7	1.00	13.9	33.3	19.9

Appendix D-8: Species Composition and Abundance in Black Spruce, Plot 8, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Mertensia paniculata	2.00	100	0.80	100	60.0	100
Low Herb						
Carex spp.	0.40	0.96	0.20	2.82	20.0	8.33
Cornus canadensis	2.00	4.81	0.40	5.63	40.0	16.7
Linnaea borealis	9.80	23.6	2.20	31.0	80.0	33.3
Mitella nuda	29.2	70.2	4.20	59.2	80.0	33.3
Pteridophytes						
Equisetum scirpoides	0.20	0.48	0.10	1.41	20.0	8.33

Appendix D-9: Species Composition and Abundance in Black Spruce, Plot 9, 1977

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Vaccinium myrtilloides	1.83	100	1.75	100	66.7	100
Low Herb						
Cornus canadensis	1.33	12.1	1.30	17.2	50.0	27.3
Goodyera repens	0.67	6.09	1.00	13.2	16.7	9.13
Linnaea borealis	1.00	9.09	1.00	13.2	16.7	9.13
Smilacina trifolia	1.33	12.1	2.00	26.5	33.3	18.2
Vaccinium vitis-idaea	6.67	60.6	2.25	29.8	66.7	36.4

Appendix D-10: Species Composition and Abundance in Black Spruce, Plot 1, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Shrubs						
Alnus crispa	1.50	81.97	4.50	51.90	50.00	75.00
Salix spp.	0.33	18.03	4.17	48.10	16.67	25.00
Tall Herb						
Ledum groenlandicum	0.83	8.58	1.00	13.32	33.33	15.38
Mertensia paniculata	0.17	1.76	0.17	2.26	16.67	7.69
Petasites palmatus	5.67	58.63	1.67	22.24	100.00	46.15
Rosa acicularis	3.00	31.02	4.67	62.18	66.67	30.77
Low Herb						
Achillea millefolium	2.83	1.10	0.50	0.30	50.00	5.66
Arctostaphylos rubra	0.83	0.31	0.83	0.50	50.00	5.66
Carex disperma			11.67	7.02	83.33	9.43
Carex trisperma			5.00	3.01	50.00	5.66
Cornus canadensis	87.67	32.73	33.33	20.04	100.00	11.32
Fragaria vesca	1.83	0.68	0.50	0.30	16.67	1.89
Fragaris virginiana	13.00	4.85	5.67	3.41	83.33	9.43
Galium trifolium	0.17	0.06	0.17	0.10	16.67	1.89
Linnaea borealis	52.67	19.67	25.83	15.53	83.33	9.43
Mitella nuda	100.50	37.52	21.50	12.93	100.00	11.32
Pyrola secunda	0.33	0.12	0.17	0.10	16.67	1.89
Smilacina trifolia	6.00	2.24	1.67	1.00	50.00	5.66
Vaccinium oxycoccus	0.17	0.06	0.17	0.10	16.67	1.89
Viola pallens	0.67	0.25	0.17	0.10	16.67	1.89
Pteridophytes						
Equisetum arvense	0.83	0.31	0.50	0.30	16.67	1.89
Equisetum scirpoides			58.33	35.07	100.00	11.32
Equisetum sylvaticum	0.33	0.12	0.33	0.20	33.33	3.77

Appendix D-11: Species Composition and Abundance in Black Spruce, Plot 2, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Epilobium angustifolium	0.17	0.61	0.17	0.63	16.67	9.09
Ledum groenlandicum	24.00	86.74	23.50	86.46	83.33	45.45
Petasites palmatus	1.83	6.61	1.67	6.14	16.67	9.09
Rubus chamaemorus	1.50	5.42	1.67	6.14	50.00	27.27
Vaccinium myrtilloides	0.17	0.61	0.17	0.63	16.67	9.09
Low Herb						
Carex disperma	4.17	1.29	0.66	0.83	16.67	4.55
Cornus canadensis	17.83	5.53	6.83	8.63	100.00	27.27
Linnaea borealis	16.67	5.17	3.50	4.42	50.00	13.64
Vaccinium oxycoccus	73.50	22.81	15.00	18.95	16.67	4.55
Vaccinium vitis-idaea	204.17	63.37	50.17	63.38	100.00	27.27
Pteridophytes						
Equisetum scirpoides	2.33	0.73	1.17	1.48	50.00	13.64
Equisetum sylvaticum	3.50	1.09	1.83	2.31	33.33	9.09

Appendix D-12: Species Composition and Abundance in Black Spruce, Plot 3, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Aster spp.	0.50	19.92	0.17	11.26	16.67	20.00
Actaea rubra	0.17	6.78	0.83	54.97	16.67	20.00
Ribes glandulosum	0.67	26.69	0.17	11.26	16.67	20.00
Solidago hispida	1.00	39.84	0.17	11.26	16.67	20.00
Vaccinium myrtilloides	0.17	6.78	0.17	11.26	16.67	20.00
Low Herb						
Carex disperma	2.17	2.83	0.83	4.33	16.67	4.35
Cornus canadensis	27.00	35.21	9.50	49.53	66.67	17.39
Fragaria vesca	0.33	0.43	0.17	0.89	16.67	4.35
Fragaria virginiana	0.17	0.22	0.17	0.89	16.67	4.35
Goodyera repens	5.67	7.39	0.83	4.33	66.67	17.39
Linnaea borealis	8.67	11.31	1.67	8.71	66.67	17.39
Mitella nuda	30.17	39.35	5.17	26.96	33.33	8.70
Pyrola virens	1.50	1.96	0.17	0.89	33.33	8.70
Smilacina trifolia	0.17	0.22	0.17	0.89	16.67	4.35
Viola pallens	0.33	0.43	0.33	1.72	33.33	8.70
Pteridophytes						
Equisetum sylvaticum	0.50	0.65	0.17	0.89	16.67	4.35

Appendix D-13: Species Composition and Abundance in Black Spruce, Plot 4, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Epilobium angustifolium	0.33	2.23	0.33	2.28	33.33	18.18
Ledum groenlandicum	6.67	44.98	11.67	80.54	16.67	9.09
Petasites palmatus	0.50	3.37	0.33	2.28	33.33	18.18
Rosa acicularis	5.00	33.72	1.33	9.18	83.33	45.45
Vaccinium myrtilloides	2.33	15.71	0.83	5.73	16.67	9.09
Low Herb						
Arctostaphylos rubra	1.00	0.31	0.33	0.47	33.33	6.17
Carex disperma			23.67	33.88	83.33	14.28
Cornus canadensis	25.83	8.01	3.67	5.25	100.00	17.14
Fragaria vesca	1.00	0.31	0.17	0.24	16.67	2.86
Galium trifolium	0.67	0.21	0.17	0.24	16.67	2.86
Linnaea borealis	8.17	2.53	1.00	1.43	33.33	5.71
Mitella nuda	20.17	6.25	1.17	1.67	83.33	14.28
Vaccinium oxycoccus	1.83	0.57	0.17	0.24	16.67	2.86
Vaccinium vitis-idaea	247.33	76.69	37.50	53.68	100.00	17.14
Pteridophytes						
Equisetum scirpoides	14.33	4.44	1.34	1.91	33.33	5.72
Equisetum sylvaticum	2.17	0.67	0.67	0.96	66.67	11.43

Appendix D-14: Species Composition and Abundance in Black Spruce, Plot 5, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Ledum groenlandicum	33.33	80.64	46.83	93.36	100.00	37.50
Petasites palmatus	0.50	1.21	0.33	0.66	33.33	12.50
Rosa acicularis	1.17	2.83	0.83	1.65	50.00	18.75
Vaccinium myrtilloides	6.33	15.32	2.17	4.33	83.33	31.25
Low Herb						
Cornus canadensis	0.83	0.32	0.33	0.45	33.33	11.76
Galium trifolium	0.17	0.07	0.17	0.23	16.67	5.88
Geocaulon lividum	1.17	0.45	0.50	0.68	50.00	17.65
Linnaea borealis	3.67	1.41	0.83	1.12	33.33	11.76
Pyrola virens	0.50	0.19	0.17	0.23	16.67	5.88
Vaccinium vitis-idaea	253.33	97.31	71.67	96.85	100.00	35.29
Pteridophytes						
Equisetum scirpoides	0.67	0.26	0.33	0.45	33.33	11.76

Appendix D-15: Species Composition and Abundance in Black Spruce, Plot 6, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Ledum groenlandicum	29.83	72.18	39.33	93.67	100.00	40.00
Petasites palmatus	7.33	17.74	1.33	3.17	100.00	40.00
Vaccinium myrtilloides	4.17	10.09	1.33	3.17	50.00	20.00
Low Herb						
Carex disperma	58.83	33.08	23.00	59.93	100.00	15.38
Cornus canadensis	14.33	8.06	2.33	6.08	83.33	12.82
Fragaria virginiana	0.17	0.10	0.17	0.44	16.67	2.56
Linnaea borealis	14.33	8.06	1.83	4.77	100.00	15.38
Mitella nuda	47.00	26.43	4.00	10.43	83.33	12.82
Pyrola secunda	1.67	0.94	0.17	0.44	16.67	2.56
Pyrola virens	1.00	0.56	0.17	0.44	16.67	2.56
Smilacina trifolia	0.17	0.10	0.17	0.44	16.67	2.56
Vaccinium vitis-idaea	27.83	15.65	3.33	8.69	50.00	7.69
Viola pallens	0.33	0.19	0.17	0.44	16.67	2.56
Pteridophytes						
Equisetum sylvaticum	4.67	2.63	1.17	3.05	66.67	10.26
Equisetum scirpoides	7.50	4.22	1.83	4.77	83.33	12.82

Appendix D-16: Species Composition and Abundance in Black Spruce, Plot 7, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Rosa acicularis	0.17	100.00	0.17	100.00	16.67	100.00
Low Herb						
Cornus canadensis	8.83	26.36	3.33	26.30	66.67	33.34
Geocaulon lividum	19.67	58.72	8.83	69.75	100.00	50.00
Linnaea borealis	5.00	14.93	0.50	3.95	33.33	16.67

Appendix D-17: Species Composition and Abundance in Black Spruce, Plot 8, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Epilobium angustifolium	0.20	6.67	0.20	12.50	20.00	14.29
Mertensia paniculata	1.80	60.00	0.60	37.50	40.00	28.57
Petasites palmatus	0.20	6.67	0.20	12.50	20.00	14.29
Rosa acicularis	0.40	13.33	0.40	25.00	40.00	28.57
Vaccinium myrtilloides	0.40	13.33	0.20	12.50	20.00	14.29
Low Herb						
Carex disperma	1.00	2.65	0.60	15.00	60.00	20.00
Cornus canadensis	2.20	5.82	0.40	10.00	40.00	13.33
Linnaea borealis	14.20	37.57	0.80	20.00	80.00	26.67
Mitella nuda	14.60	38.62	1.60	40.00	60.00	20.00
Vaccinium vitis-idaea	2.60	6.88	0.20	5.00	20.00	6.67
Pteridophytes						
Equisetum scirpoides	3.20	8.47	0.40	10.00	40.00	13.33

Appendix D-18: Species Composition and Abundance in Black Spruce, Plot 9, 1982

Species	Density	Relative Density (%)	Dominance	Relative Dominance (%)	Frequency	Relative Frequency (%)
Tall Herb						
Vaccinium myrtilloides	5.00	100.00	4.00	100.00	66.67	100.00
Low Herb						
Cornus canadensis	3.00	20.45	2.17	50.00	66.67	30.77
Goodyera repens	1.00	6.82	0.17	3.92	16.67	7.69
Linnaea borealis	0.50	3.41	0.17	3.92	16.67	7.69
Smilacina trifolia	1.17	7.98	0.50	11.52	33.33	15.38
Vaccinium vitis-idaea	9.00	61.35	1.33	30.65	83.33	38.46